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Design and Analysis of Planetary Gear and Track Hybrid Mobile Robot

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Abstract: In order to improve the ability of obstacle negotiation and stability of mobile robot under unstructured environment, a new type of planetary gear and track hybrid mobile robot has been designed. This robot can surmount lower obstacles by its gravity and inertia of epicyclic gear train, otherwise, higher obstacles can be negotiated by the track arms. The two-part body connected by universal coupling can adjust to different terrain. Also, key parts of the robot were analyzed by ANSYS. According to the analysis results, an optimization design has been put forward .The analysis results can be concluded that the total deformation of the track arm can be reduced from 289 μm to 41.9 μm and the stiffness was improved. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Planetary gear and track hybrid mobile robot, Mobile robot, ANSYS, Finite element analysis.

1. Introduction

Robot has been used wide to almost every field. Mobile robot is only one important branch of Robotics. Early from 1960s, research on mobile robot has started. Until now, it has gained many achievements. Most researches of mobile robots focused on wheeled, tracked and legged mobile chassis. Wheeled robots can move at a high speed and has the inferior adaptability to rough terrain. Tracked robots can easily adapt to uneven terrain, but more power is consumed by the heavy chassis. Legged robots have better abilities of ground adaptability and obstacle negotiation with the complex mechanical and control system [1-3].

Hybrid mobile robot is integrated with all advantages of different kinds of chassis, thus it has been the important research trend. A new type of planetary gear and track hybrid mobile robot was put forward in this paper and combined the advantages of wheeled and tracked chassis. Additionally, the two-part body can adjust the gravity center to rough terrain [4-6].

2. Mechanical Design

The mobile robot employs two planetary gear trains, two passive wheels, two track arms and the two-part body (see Fig. 1). The planetary gear train is used as the main locomotion and obstacle-negotiation mechanism, thus the front-wheel differential drive is adopted in the mobile robot. The low reduction ratio of the planetary gear train makes the robot compacted. The limited rotation angle of the track arm is 220°and the speed is 10°per second. Because of the low speed and the limitation of size and gravity, we use the low-speed motor and harmonic gear reducer with the reduction ratio of 30. Thus more torque can be provided for the track arm to support the chassis.

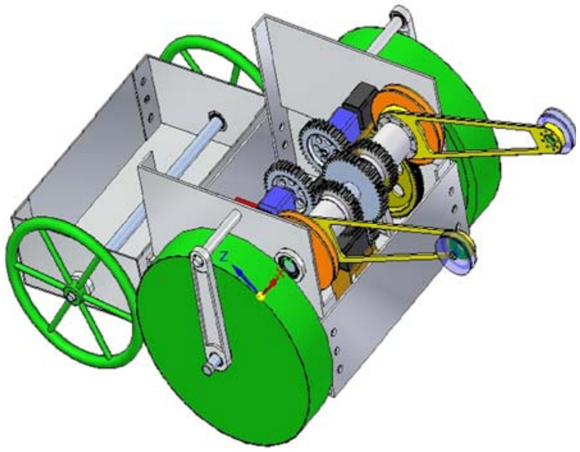
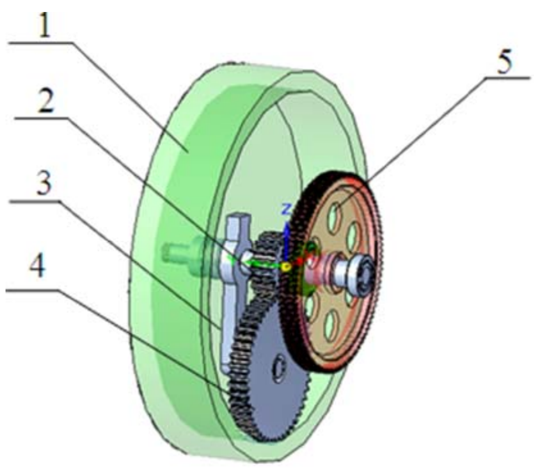


Fig. 1. Planetary gear and track hybrid mobile robot.

2.1. Planetary Gear Train

In order to take advantages of wheeled chassis, the planetary gear and track hybrid mobile robot employs the planetary gear train as the main locomotion mechanism (see Fig. 2) [7, 8]. Meanwhile, the planetary gear train can be used to climb obstacles by regulate the gravity center. Under structured environment, the planetary gear 4 is located in the lowest point due to gravity. The planetary gear train is working as a fixed axis gear train and the sun gear 2 makes the internal gear 1 move by the planetary gear 4. According to the formula $\frac{z_1}{z_2} = \frac{w_2}{w_1}$, the speed of internal gear is 100 r/min and the top speed of the robot is $7.5Km / h$.



1 – The internal gear, 2 – The sun gear, 3 – Planet carrier, 4 – The planetary gear, 5 – Reduction gear

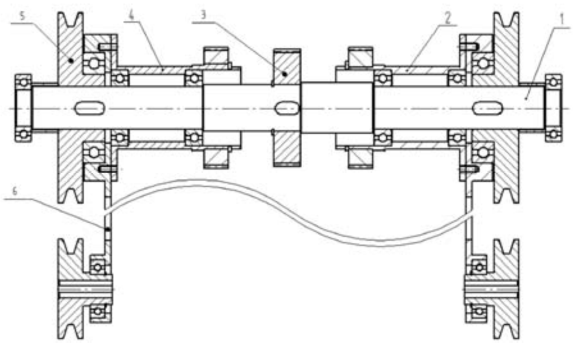
Fig. 2. Planetary gear train.

When the internal gear gets stuck by obstacle with the height lower than the radius of the internal gear, the planetary gear train works as an epicyclic gear train and the planetary gear rotates and revolutes along the internal gear. Consequently, the mobile robot climbs obstacles with the gravity center raised [9].

2.2. Track Arm

The track arm is used to climb higher obstacles (see Fig. 3). Besides the swing of the arm, the track wheel also rotates during obstacle negotiation. Because the rotation axis of the arm and the swing axis of the track wheel are the same, the inner-and-outer shaft is employed to transmit two different kinds of motion. The bearings are installed between the inner shaft and the outer one, thus the inner or outer shaft can rotate relatively. The outer shaft is fixed on the retainer 6 by dowels and is driven by the drive gear 4. As a result, the retainer can keep swinging. The inner shaft, connected with the track drive gear 3 and the track wheel 5 by keys, is driven by the track drive gear 3 and then makes the track run. The retainer connects the track wheel by bearing, thus they can run independently [10].

When obstacles are higher than the radius of the internal gear, the track arm works. The drive gear 4 makes the arm against the obstacle and then the chassis is lifted up. Meanwhile the track drive gear 3 makes the track run, thus the mobile robot finish obstacle negotiation by the friction force [10-12].



1 – Principal axis, 2 – Sleeve, 3 – Track drive gear, 4 – Swing drive gear, 5 – Track wheel, 6 – Retainer

Fig. 3. Structure of the track arm.

2.3. The Two-part Body

The two-part body is adopted by the mobile robot, and the former and later body is connected by the universal coupling. The angle between the former and later body can be adjusted by terrains, thus the gravity center of the mobile robot is much lower and more stable in rough terrains [13].

3. Finite Element Analysis

In this paper CAD model is designed in Solid Edge ST-III and finite element analysis is made in

ANSYS Workbench 14.5. When the CAD model is imported into ANSYS Workbench, the model should be converted into a compatible file format, such as Parasolid, STEP, IGES.

3.1. Finite Element Analysis of the Retainer

As one important part of the robot, the track arm bears much load during climbing obstacles, thus the stiffness and stability of the retainer, as showed in Fig.4, is vital [14, 15].

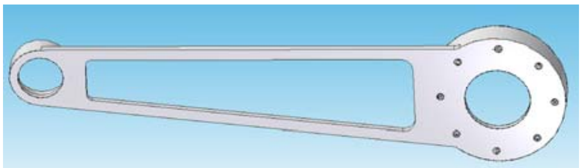


Fig. 4. 3D model of retainer.

The retainer is made of aluminum alloy with the density of 2700 Kg/m^3 and the Poisson's ratio of 0.33. The automatic meshing is adopted.

The retainer connects the outer draft by bolts, and the outer draft is driven by the reduction gear. During obstacle negotiation, the retainer lifts up the whole chassis, so the force acts on the bolts. The retainer was analyzed in the horizontal position when the retainer is exerted the maximum force.

From Fig. 5 and Fig. 6, we know the maximum stress is 33.8 MPa, and the maximum deformation is 289 μm. So we can draw a conclusion that the retainer's deformation is too large and the stress is suitable during climbing obstacles. Thus the retainer should be optimized because its stiffness is under demand [16].

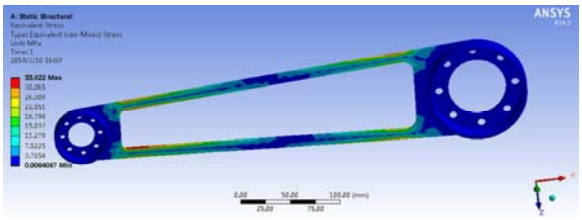


Fig. 5. Strain of retainer.

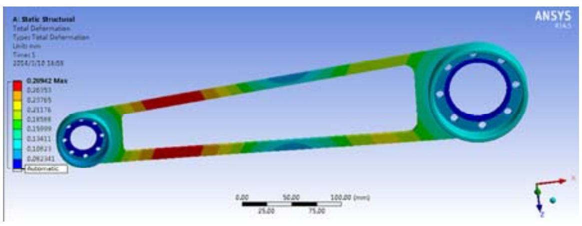


Fig. 6. Deformation of retainer.

3.2. Finite Element Analysis of the Principal Axis

The principal axis was exerted the force from the track arm and the torque from the drive gears during obstacle negotiation. From static analysis, we make a conclusion that the maximum force and torque occur when the principal axis is horizontal. The principal axis's material is 45 steel and Poisson's ratio is 0.277. The deformation of axle is shown in Fig. 7.

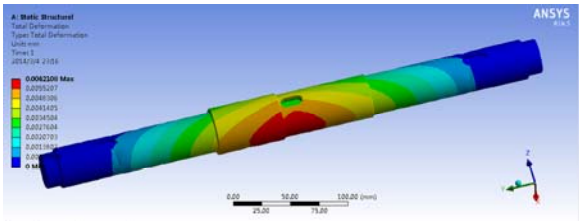


Fig. 7. Deformation of axle.

From Fig. 7, we concluded that the maximum deformation is 4.2 μm, and will not affect the obstacle-negotiation ability of the mobile robot. So the design of the principal axis meets the requirement.

3.3. Finite Element Analysis of the Planetary Gear Train

The planetary gear train is the main locomotive mechanism of the mobile robot as Fig. 2. It bears torque during the obstacle negotiation. From the formula $T = 9550 \dfrac{P(Kw)}{n(r/\min)}$, each gear's torque can be calculated and the result is shown in Table 1 [17, 18].

Table 1. Torque of the epicyclic gear train.

	Sun gear	Planet gear	Internal gear
Rotate speed (r/min)	600	240	100
Torque (N·m)	7.9583	19.896	47.749
Number of teeth	20	50	120
Modulus (M/mm)	3	3	3
Pressure angle (°)	20	20	20
Tooth thickness (mm)	22	20	40

The planetary gear train's material is 40 Cr with the density of $7850 Kg/m^3$, the flexural strength of 600 MPa and the Poisson's ratio of 0.277. In view of accuracy and computational efficiency, the automatic meshing method was adopted for the whole solid and further mesh refinement for the connecting area [19, 20]. The results are shown in Fig. 8 and Table 2 [21, 22].

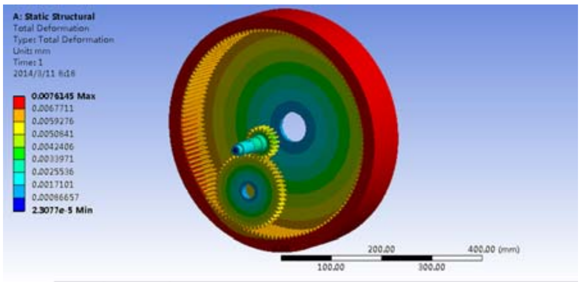


Fig. 8. The total deformation of planetary gear.

Table 2. Finite element analysis of planetary gear.

	Sun gear	Planet gear	Internal gear
Maximum stress (MPa)	55.6	46.7	24.7
Maximum deformation (μm)	5.92	6.22	7.61

From Table 2, we can conclude that the maximum deformation is 7.61 μm at the contour portion of the internal gear and the design of the planetary gear train meets the requirement.

3.4. Mechanism Optimization Analysis

From Fig. 6, we can conclude that the maximum deformation is located in the middle part of the retainer. If the material of aluminum alloy was replaced with structural steel to improve the stiffness of the retainer, the gravity of the retainer would arise greatly. So the three supporting mechanism were added to the retainer without changing the material. Thus the result was shown in Fig. 9.

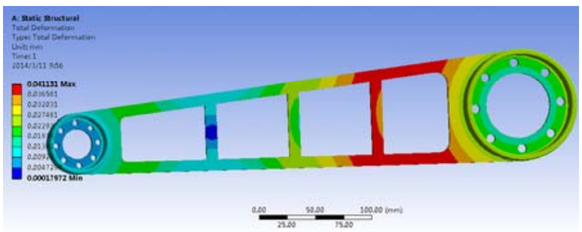


Fig. 9. Finite element analysis of optimized retainer.

Now the maximum deformation is 41.1 μm, and stiffness has been enhanced. So the optimization design meets the requirement.

4. Conclusion

We proposed a new type of mobile robot with good ability of obstacle negotiation and stability, and we analyzed it's feasibility of the design and optimization. We accomplished the CAD model and finite element analysis by ANSYS and then we make some improvements. In the end, we drew some conclusions.

1. The planetary gear and track hybrid mobile robot has two ways of obstacle negotiation. When the height of obstacle is lower than the radius of the internal gear, the planetary gear train can accomplish the obstacle negotiation. Otherwise, the track arm was adopted to cross obstacles. By combining these two methods, the mobile robot's ability of obstacle negotiation has been improved.
2. The two-part body makes the mobile robot easy to adapt to rough terrains. The lower center of gravity makes the robot more stable. Meanwhile, the chassis can adjust to ascend and descent steep slopes.
3. The finite element analysis results reflect the design and the optimization meet the requirements.

Acknowledgements

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