Acta Technica 62 (2017), No. 5A, 723–732

Design and application of middle-supported mecanum wheels for an omni-directional wheelchair

Sumei DAI[2], Yunwang LI[3,4], Feng TIAN[3]

Abstract. This paper introduces a kind of Mecanum wheels for an omnidirectional wheelchair that not only can move in any direction, but also has a certain off-road performance. In order to design this Mecanum wheel, the structural forms of the common Mecanum wheels and their respective advantages and disadvantages are analyzed firstly in this paper. According to the analysis results, the middle support type Mecanum wheel is suitable for the wheelchair. A type of welded rim and a kind of vulcanized rubber roller were designed. The Mecanum wheel was developed by using the rim and rollers. The prototype of the wheelchair has been processed using the wheel and the mobile performance test was carried out. The experiment of omni-directional movement on the flat ground shows that the mobile platform is able to achieve more accurate omni-directional movement. The Terrain trafficability test was carried out on the outdoor rough terrain. This test shows that the wheelchair can be passively adapted to the uneven terrain and has good off-road property. By testing the wheelchair, the terrain adaptability of the middle support type Mecanum wheel and the rationality of the design were verified.

Key words. Mecanum wheel, middle support type, Welded rim, omnidirectional wheelchair.

1. Introduction

Mecanum wheel, a kind of omni-directional wheel, is usually used on the mobile platform that is needed to achieve omni-directional movements on flat surface [1-5]. The Mecanum wheels on the mobile platform should be arranged and assembled according to some reasonable schemes and driven independently. In recent years, Mecanum wheel has got a wider range of applications in the field of mobile robots

[1]Acknowledgement - In this paper, the research was sponsored by the National Natural Science Foundation of China (Project No. 51675518) and the Priority Academic Program Development of Jiangsu Higher Education Institutions.

[2]Workshop 1 - School of Mechanical and Electrical Engineering, Xuzhou Institute of Technology, Xuzhou, 221111, China

[3]Workshop 2 - School of Mechatronic Engineering, China University of Mining and Technology, Xuzhou,221116, China

[4]Corresponding author: Yunwang LI; e-mail: yunwangli@cumt.edu.cn

such a service robot and AGV robot[6-7].

There are a series of rollers attached to the circumference of the Mecanum wheel rim. The wheel rim is the assembly foundation of the rollers. These rollers can rotate around their axises freely. These rollers typically each have an axis of rotation at 45? to the plane of the wheel rim and at 45? to a line through the centre of the roller parallel to the axis of rotation of the wheel [8]. Mecanum wheels require higher manufacturing accuracy compared with ordinary wheels. The mechanical precision of the wheel rim is the guarantee of the mechanical precision and kinematic precision of the Mecanum wheel.

According to the supporting modes of the rim to the rollers, the Mecanum wheels can be divided into two kinds:the two-side support typeand the middle support type. These two types of Mecanum wheels have their own advantages and disadvantages, which are suitable for mobile platforms used in different fields. These two kinds of Mecanum wheels should be selected and applied, according to the actual requirements of the Mecanum mobile platform.

In this paper, the design, manufacture and application of a kind ofMecanum wheel are introduced.This kind of mecanum wheel, a middle support type one, is developed for an omni-directional wheelchair which not only has the performance of omni-directional movement, but also has the ability to adapt to the uneven terrain [9].

2. Selection of the Type of MecanumWheel for aWheelchair

The electric wheelchair involved in this paper can not only move in any direction, but also have certain off road performance. So, the Mecanum wheels used on the wheelchair should be selected reasonably. The common structural forms of the middle support type and two side support type Mecanum wheels are shown in Figure 1. The two side support type Mecanum wheels are shown in Figure 1 (a) to (c). The rims are designed at both sides of the wheels to support the two ends of the shaft of the rollers. Among them, the wheel rim in Figure 1 (a) is made of sheet metal, the rim in Figure 1 (b) is made of casting, the rim in Figure 1 (c) is processed by the method of material removal. The middle support type Mecanum wheels are shown in Figure 1 (d) to (f). The support components are provided in the middle of the rim of the middle support type wheel rims for supporting the middle of the roller shafts. The supporting components are evenly distributed in the middle of the rim. Among them, the wheel rim in Figure 1 (d) is made of sheet metal, the rim in Figure 1 (e) is made of casting, the rim in Figure 1 (f) is made by injection molding. The two forms of the Mecanum wheel mentioned in the previous section of this paper have their own advantages and disadvantages.

The first kind of wheels have the advantages of strong load capacity. However, the wheels have the disadvantage that, when encountering an uneven or an inclined surface, or when being tilted because of the load, the components of the outside of the rim can make contact with the ground surface or obstacles instead of the rollers, thus preventing the wheels moving correctly [10]. The situations are illustrated in Figure 2.

Fig. 1. The common structural forms of the Mecanum wheels

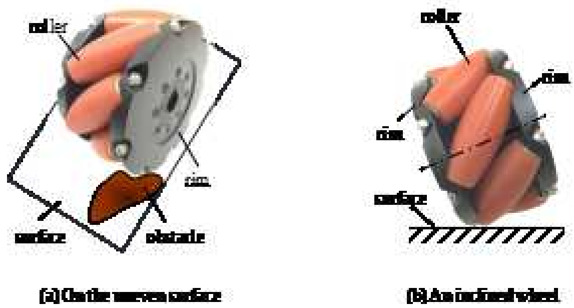

Fig. 2. The situations of movement hindered

Each type has their own characteristics. Compared with the two side support type Mecanum wheel, the middle support one has the following advantages: (1) Because the wheels has no side rim, it can avoid the collision and interference between the wheel rim and the ground or obstacles, so as to ensure the correct movement of the mobile platform. (2) Their appearance are more concise and beautiful. Therefore, for the wheelchair involved in this paper, the middle support type Mecanum wheel is a better choice.

3. Design and Manufacture of the Middle Support type MecanumWheel

(1) Structural parameters analysis of Mecanum wheel

Figure 3 is a schematic diagram of the expansion of the rollers during the running of the Mecanum wheel. From the expansion diagram, the following geometric relationships can be obtained:

$$\begin{cases} h = 2\pi \cdot r/n \\ b = l \cdot \cos\alpha \\ k = l \cdot \sin\alpha - h \\ a = 2r \cdot \cos\alpha \cdot \sin(\pi/n) - 2r_{\mathrm{r}} \end{cases} \tag{1}$$

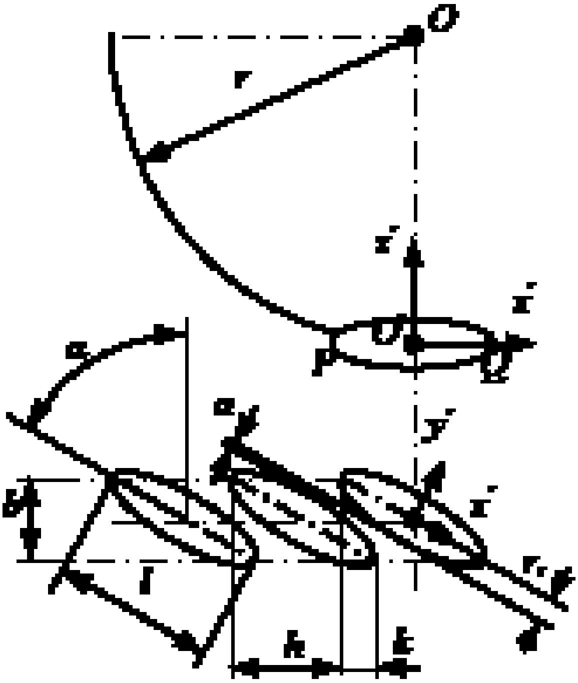

Fig. 3. The expansion diagram of rollers

Where: l is the length of the roller; r is the radius of the hub; r_r is the maximum radius of the roller; h is the roller pitch; α is the angle between the axis of the roller and the hub axis, called s the offset angle of the roller; k is the degree of overlap of the rollers, b is the width of the Mecanum wheel; a is the clearance of the rollers. n is the number of rollers of each Mecanum wheel. If k is less than 0, a complete enveloping circle can not be formed, and the bearing capacity of the Mecanum wheel increases with k. On one hand, interference between two neighboring roller may be exerted due to the deformation caused by heavy load when a is too tight, with which the roller can not turn round. On the other hand, the distance between rollers is too large to keep the continuity of the theoretical cylinder surface when a is too high. Therefore, it is critical to choose a reasonable k and a. wherein a is usually larger than or equal to 3 mm.

The outer surface of the roller of the Mecanum wheel is usually formed by a section of profile revolving around an axis. There are several ways to design the outline of the roller. The theoretical contour of the roller is an elliptic curve, which satisfies equation (2).

$$\frac{x^2}{(r_{\mathrm{r}}+r)^2}+\frac{y^2}{(r_{\mathrm{r}}+r)^2/\sin^2\alpha}=1 \tag{2}$$

The long and short semi-axes of the ellipse are $r_{\mathrm{r}}+r/\sin\alpha$and $r_{\mathrm{r}}+r$.

The Mecanum wheel in this paper is designed according to the following parameters: The radius of the Mecanum wheel $R = 140$ mm, the theoretical radius of the hub $r = 120$ mm, the maximum radius of the rollerr_r= 20 mm, the number of rollers $n = 12$, the roller length $l = 100$ mm, the offset angle α= 45?. By equation (**??**), it can be calculated that $b = 70.7$ mm, $k = 7.9$, $a = 3.9$. The calculation indicates that b is reasonable, and k, a satisfy the design principles.

(2) Design of the roller of the Mecanum wheel

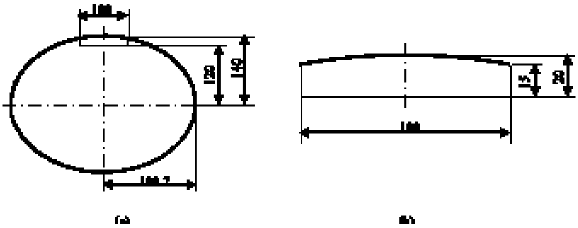

Fig. 4. The elliptical profile curve of roller

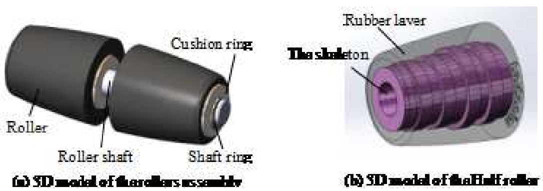

Fig. 5. The 3D models of the roller

Fig. 6. The photos of the roller

When designing the roller, the theoretical elliptical contour should be determined firstly. By equation (2), the long semi-axe of the elliptic curve is 189.7mm and the short semi-axe is 140mm, from which the outline of the roller can be obtained, as shown in Figure 4.

The roller for the middle support type Mecanum wheel should be designed into two split half rollers which are stringed by a roller shaft, as shown in Figure 5, thus the shaft can be supported by the support element between the two half rollers. The inside of the roller is a skeleton which is designed to be a round table with multi-channel grooves on the outer circle to facilitate the attachment of the outer rubber and can be made of nylon as shown in Figure 6(a). The rubber layer is vulcanized outside of the skeleton by using mold, as shown in Figure 6(b)(c). A nylon skeleton photo is shown in Figure 6(a).

(3) Design of the rim of the Mecanum wheel

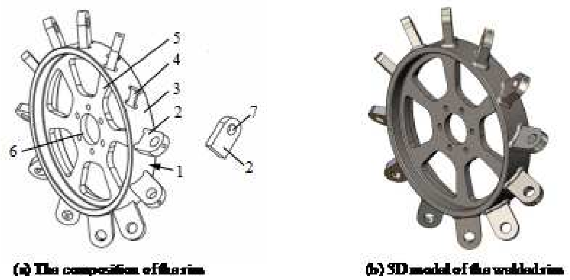

Fig. 7. The structure of the wheel rim

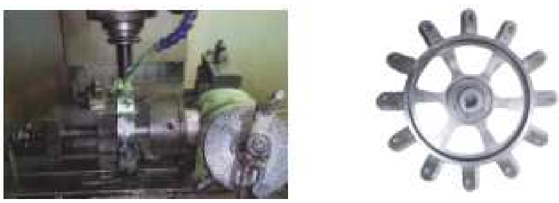

Fig. 8. The processing of positioning slots

As the base of the rollers, the machining accuracy of the rim is the guarantee of the Mecanum wheel, so the design of the rim is most critical. As shown in Figure 7 (a), the rim consists of a hub body and supporting blades for rollers. The roller deflection angle between the blade and the axis of the rim is $\pm$ 45 in this design. There are 12 rollers in this design, so 12 supporting blades should be set in the outer edge of the rim flange. In order to reduce the processing and processing costs, the rim adopts a split design, and the supporting blade is welded on the rim flange. In order to locate the supporting blade accurately before welding, 12 positioning slots distributed uniformly are processed on the outer circumference of the rim flange. After the supporting blades are placed in the positioning slots, the supporting blades are welded together with the flange. In this design, orifice plate spoke are used, and a hub hole used to connect the wheel hub is provided at the center of the spoke. There is a roller shaft mounting hole on each supporting blade to install and support the roller shaft. The 3D model of the welded rim is illustrated in Figure 7(b).

With the above scheme, the positioning slots on the rim can be processed by four axis three-dimensional machining center, also by the three axis CNC milling machine with dividing head, as shown in Figure 8. The precision of the positioning slot is guaranteed by numerical control machine tool, so the position precision of the supporting blade can be guaranteed by the precision of the positioning slot. The positioning slot is mainly used for positioning, and does not need to be processed too deep, so the machining efficiency of the rim is high. With the welding process, the number of parts of the rim can be reduced and the strength of the rim can be guaranteed. In this way, the assembly can be simplified, and the appearance of the rim is simple and beautiful. A rim that has been connected to the hub is shown in Figure 9.

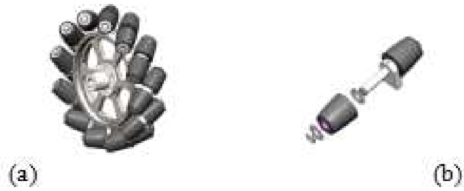

Fig. 9. Assembly of the Mecanum wheel

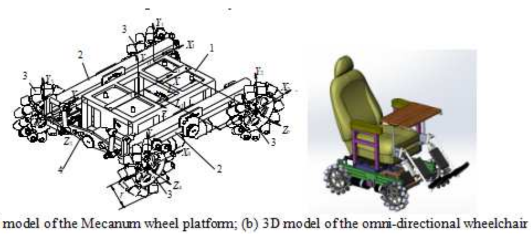

Fig. 10. The 3D models of the Mecanum wheel platform and the omni-directional wheelchair

4. The applicationand test of the Mecanum wheel

The assembly of a middle support type Mecanum wheel using the rim is shown in Figure 10. The Mecanum wheel platform (MWP) for omni-directional wheelchair in this paper is mainly composed of four parts: main body, two rocker arms, four Mecanum wheels and differential mechanism, as is shown in Figure 11. The components such as battery, electrical components are placed in the main body. The rocker arms and differential mechanism are used to combine the main body and the four Mecanum wheels that are driven independently. With the differential mechanism, the platform can adapt to terrain passively, the four wheels can keep connection with the ground simultaneously, the load of the four wheels is approximately equal. The platform can move omni directionally with the Mecanum wheels. The 3D virtual prototype model of the MWPand the omni-directional wheelchair are shown in Figure 11.

Fig. 11. Wheelchair lateral movement test

Fig. 12. Test on the adaptability to the uneven terrain

The prototype of the wheelchair has been processed and the mobile performance test was carried out. The experiment of omni-directional movement on the flat ground shows that the mobile platform is able to achieve more accurate omni-directional movement. Figure 12 shows the lateral motion of the wheelchair. The Terrain trafficability test was carried out on the outdoor rough terrain. The test shows that the wheelchair can be passively adapted to the uneven terrain and has good off-road property. Figure 13 shows the test on the adaptability to the uneven terrain. By testing the wheelchair, the terrain adaptability of the middle support type Mecanum wheel and the rationality of the design were verified.

5. Conclusion

This paper introduces a kind of Mecanum wheels for an omnidirectional wheelchair that not only can move in any direction, but also has a certain off-road performance. In order to design the Mecanum wheel, the structural forms of the common Mecanum wheels and their respective advantages and disadvantages are analyzed firstly in this paper. According to the analysis results, the middle support type Mecanum wheel is suitable for the wheelchair. A type of welded rim and a kind of vulcanized rubber roller were designed, and the processing methods of rims and rollers are also introduced. The Mecanum wheel was developed by using the rim and rollers. The prototype of the wheelchair was processed using the wheel and the mobile performance test was carried out. The experiment of omni-directional movement on the flat ground shows that the mobile platform is able to achieve more accurate omni-directional movement. The Terrain trafficability test was carried out on the outdoor rough terrain. This test shows that the wheelchair can be passively adapted to the uneven terrain and has good off-road property. By testing the wheelchair, the terrain adaptability of the middle support type Mecanum wheel and the rationality of the design were verified.

References

[1] Gfrerrer. A: *Geometry and kinematics of the Mecanum wheel*. Computer Aided Geometric Design *25* (2008), No. 9, 784–791.

[2] Lin. L. C, Shih. H. Y: *Modeling and Adaptive Control of an Omni-Mecanum-Wheeled Robot*. Intelligent Control & Automation *2013* (2013), No. 2, 166–179.

[3] A. Shimada, S. Yajima, P. Viboonchaicheep: *Mecanum-wheel vehicle systems based on position corrective control.* Conference of IEEE Industrial Electronics Society (2005) 6.

[4] Cooney. J. A, Xu. W. L, Bright. G: *Visual dead-reckoning for motion control of a Mecanum-wheeled mobile robot.* Mechatronics *14* (2004), No. 6, 623–637.

[5] MO. Tatar, C. Popovici, M. Dan, I. Ardelean: *A Plesa Design and development of an autonomous omni-directional mobile robot with Mecanum wheels.* IEEE International Conference on Automation (2014) 1–6.

[6] V. Alakshendra, S. S. Chiddarwar: *Adaptive robust control of Mecanum-wheeled mobile robot with uncertainties.* Nonlinear Dynamics *87* (2017), No. 4, 2147–2169.

[7] Y. Tian, S. Zhang, J. Liu, F. Chen, L. Li: *Research on a new omnidirectional mobile platform with heavy loading and flexible motion.* Advances in Mechanical Engineering *9* (2017), No. 9, 555–563.

[8] Y. F. Zhou, Z. M. Wang: *The Design and Development of an Omni-Directional Mobile Robot Oriented to an Intelligent Manufacturing System.* Sensors *17* (2017), No. 9, 2073.

[9] M. Pecka, K. Zimmermann, M. Reinstein, T. Svoboda: *Controlling Robot Morphology From Incomplete Measurements M Pecka.* Indian Journal of Pure and Applied Mathematics *34* (2003), No. 4, 587–606.

[10] R. Lal, Y. Kumar: *Sylvester Tlale. Improved Mecanum Wheel Design for Omnidirectional Robots.* Proc. 2002 Australasian Conference on Robotics and Automation *20*, (2013), No. 4, 264–275.

[11] Y. Kumar: *Modelling of a mecanum wheel taking into account the geometry of road rollers.* IJ Applied Mechanics and Engineering *18* (2013), No. 2, 589–597.

[12] J. R. Kuttler, V. G. Sigillito: *Modeling and Control of an Omni-directional Mobile Robot.* J Sound and Vibration *78* (1981), No. 4, 585–590.

Received November 16, 2017