Optimization of Mecanum Wheels for Mitigation of AGV Vibration

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Abstract— **Mecanum Wheels (MWs) consist of a series of rubber-covered rollers obliquely attached to the circumference of the wheel rim. When an MW spins, the propelling force is generated only in the direction of the roller axis. Thus, by commanding the wheels to spin in various combinations of directions, the vehicle can move in different patterns of motion. Such kinematic characteristics make MW a popular element for automated ground vehicles (AGVs) and autonomous mobile robots (AMRs). However, though the outer profile of the rollers is designed to make the circumference of MW a perfect circle, regular vibration is often witnessed when the MW rolls on the ground. In this article, we investigated the phenomenon and proposed a solution to the problem. Structural analyses confirmed that the irregular rubber stiffness surrounding the MW may result in the vibration. A design optimization task was formed to achieve uniform stiffness by changing the geometry of the metal core and the rubber layer. The final design was arrived at after a series of 3D finite element analyses.**

I. INTRODUCTION

With the booming development of Industry 4.0 at present, Mecanum wheels (MWs) are frequently applied in autonomous mobile robots (AMRs) and automated guided vehicles (AGVs), as MWs have high loading capacities and positioning precision. MWs have considerable potential for future development, but there are still problems to overcome. The vibration occurs when MWs are moving at different running speeds and frequencies. The vibration of the AGVs has an effect on the integrity of the machine structure, which in turn affects goods carried, such as wafers, fragile articles, etc.

Solving the vibration problem induced by MWs will enhance the potential of development for MWs. Take a wafer plant for instance, when an AGV is running, the stability and speed of the running AGV have to be maintained at a certain level to prevent wafers from damage during transportation. In this article, the running kinetics and rubber roller deformation of MWs are investigated. In addition, the actual situation of rollers in contact with the ground was studied to find the main cause of vibration. Specifically, the deformation of rubber rollers subject to force was calculated and results indicated that MWs have inconsistent compressive stiffness at different angles. Hence, the profile of the steel core of the rubber-covered rollers was modified to achieve MW stiffness consistency by changing the rubber thickness, thereby reducing vibration generated by the running MWs

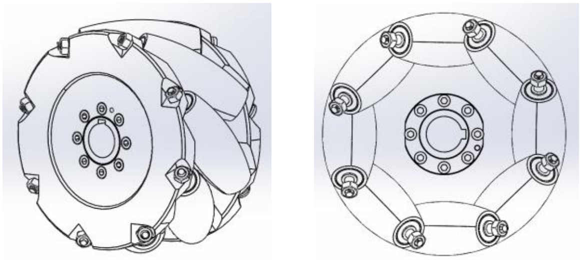

Fig. 1. A typical design of the Mecanum Wheel, which consists of multiple rubber-covered rollers trimmed to exhibit a circular circumference.

II. RELATED WORKS

From existing literature, it can be found that most studies on MWs focus on kinematics-related analysis. For example, [1-3] explained the kinematics of MWs and studied the roller loads and traction. Dickerson et al. [1] explained how the use of MWs in AGV can enhance maneuverability in a crowded space. Additionally, the algorithm for converting an expected path into the motion required is also applicable for compensation for roller displacement detection and correction. Li et al. [3] modeled and simulated the kinematics of MWs, which included the design of shock absorbers. Two swing arms were used to make rollers adhere closely to the floor to prevent the occurrence of suspension in midair, and effectively reducing roller sliding that affects the control program.

[4] and [5] researched the characteristics of the rubber-covered rollers. Different job characteristics affect the requirement on rubber performance and in turn affect the mechanics and contact characteristics of the structure. The hyperelasticity of rubber determines its ability to resist elastic deformation. An increase in the degree of compression indicates an increase in the applied load. With an increase in the applied load, the contact area and stress of rollers become greater. [6] analyzed the cylindrical rubber roller using finite element modeling to simulate deformation caused by static and rolling contact.

[7-9] reported the studies on the physical characteristics of rubber that affect the characteristics of rubber deformation, such as what displacement and deformation are caused by compression, extension, or bending. Parish et al., [8] studied rubber and iron rollers subjected to force and stress. While subjected to different widths, the thickness is the key parameter that affects the deformation curve. Our results

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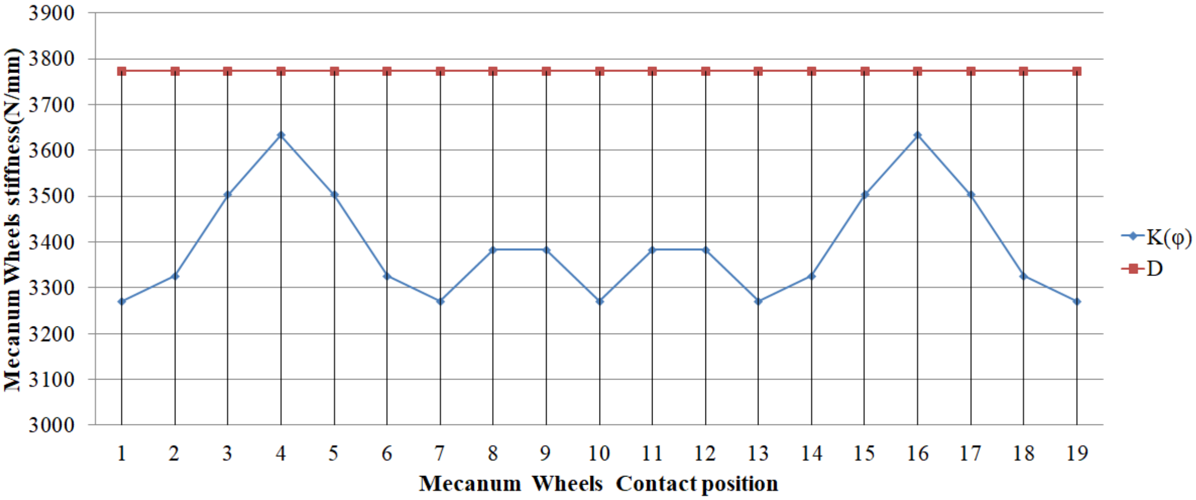

Fig. 2. Estimation of the roller stiffness at different contact positions of the MW.

detailed below confirmed the findings. Koh et al., [9] explained in their study the effect of the incompressibility of rubber. Due to the restricted lateral expansion, the compression stiffness of the bonded layer increased, which also affected the rubber deformation.

III. ANALYSIS

The MW samples used in this study were 203 mm in wheel outer diameter and 105 mm in wheel width. The sample (HIT203AHD) was provided by Hickwall Tech Caster Industrial Co., Ltd. The samples are widely used in industry and with high representativeness. It is made of eight rollers installed at 45-degree angles. From the lateral side of the MWs, each roller's arch is connected to form a perfect circle (see Fig. 1). However, the rollers showed height differences at the times of alternation. The subsequent research results show that the height difference came from the deformation of the rubber-covered rollers. Our research goal was to achieve uniform deformation at each angle by changing the geometric design of the MWs. As a result, the MWs will not cause vertical vibrations due to the height difference.

Specifically, when adjacent rollers are in transition, deformation of the first roller causes the succeeding roller to contact the ground before planned. Thus, there become two contact regions. As will be clearer later, it was found that during this period, the deformation is the lowest, signifying an increase in the overall stiffness. Based on this finding, it was confirmed that the MWs operating under the same load will exhibit different compressive stiffness at different angles. Fig. 2. shows the analysis results of the overall compression stiffness of the MW at various angles using a three-dimensional finite element model. It was found that the compression stiffness varies between 3270 N/mm and 3633 N/mm. In order to design an ideal MW, the following design optimization task was carried out for the purpose of achieving consistent compression stiffness for all angles.

A. *Design Optimization*

The optimization formulation of the current problem is,

$$\text{Minimize:} \quad \mathcal{D} = \oint |k_s - k(\varphi)|\, d\varphi$$
$$\text{Subject to:} \quad \Delta\sigma + \mathbf{F} = 0$$

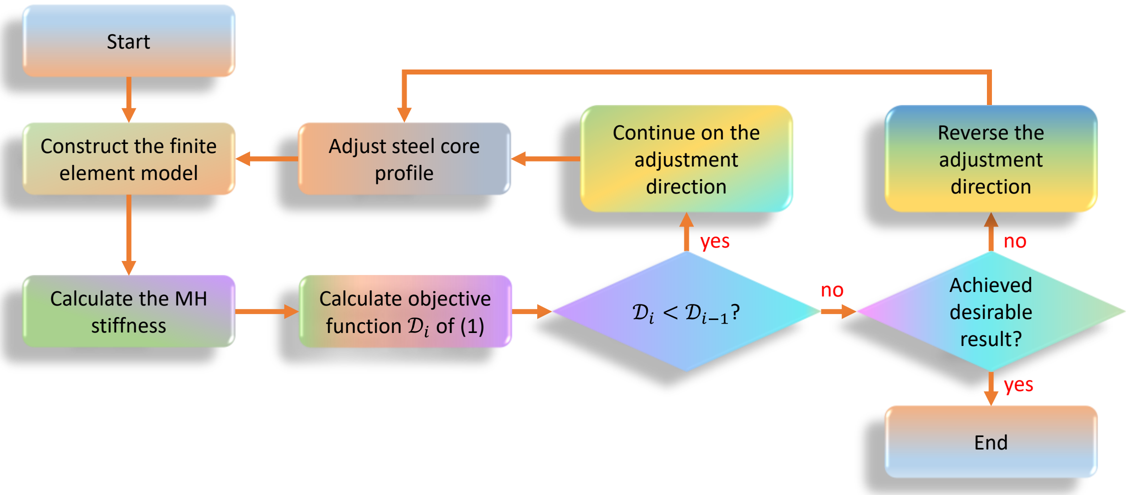

Fig. 3. Block diagram of the iteration process for design optimization of the Mecanum Wheel.

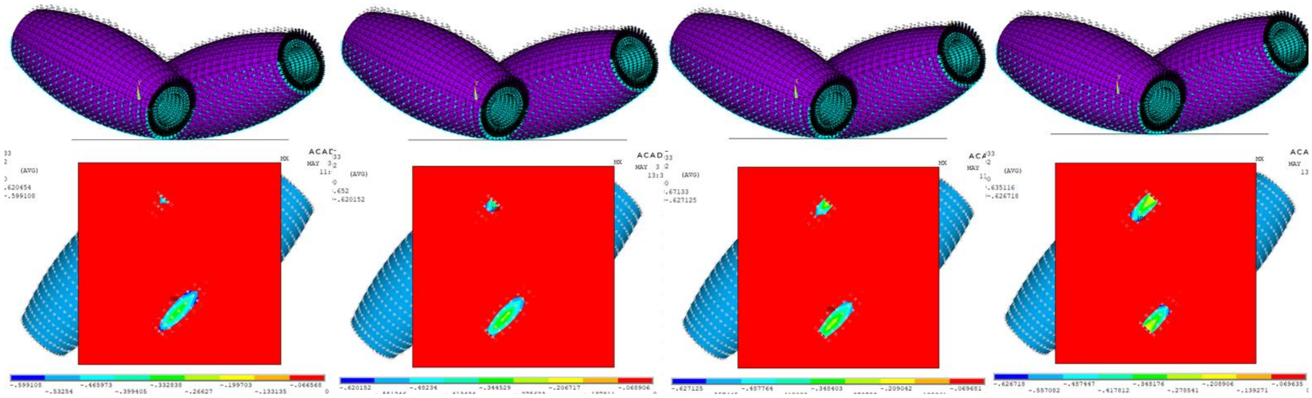

Fig. 4. Finite element results of contact stress during the transition period of two adjacent rollers. *Top*: the 3-dimensional finite element model with dual rollers; *bottom*: the contact area and stress distribution shown by the finite element results.

$$R(\varphi) \le R_s \qquad (1)$$

where k_s denotes a desirable stiffness constant of the MW, $k(\varphi)$ denotes the stiffness of the MW at different angles. $\mathcal{D}$ denotes the deviation measure evaluated across the entire circumference of the MW. $R(\varphi)$ denotes the radius of the MW at different angles; R_s denotes the maximum allowable radius.

B. Design Iteration

The optimization task outlined above was performed through an iteration process illustrated in Fig. 3. We first construct a three-dimensional finite element model that includes two full rubber-covered rollers adjacent to one another. Details of the finite element model will be provided in the following section. Each finite element model reflects the current geometry of the steel core and the rubber cover of the roller to be evaluated. We designated 10 points of contact on the model and calculated the stiffness at each contact point. Once the stiffness values are obtained, the objective function in (1) would be evaluated under a discretized form. In the next round of iteration, the outer profile of the steel core would be adjusted, resulting in a variation in the geometry of the rubber cover, particularly the thickness at different locations. As the goal of optimization is to obtain a uniform stiffness around the entire circumference of the MW, the rubber thickness is in principle, increased if the local stiffness is too high, and vice versa. After each iteration, the current value of the objective function $\mathcal{D}_i$ would be compared with $\mathcal{D}_{i-1}$ of the previous round. If an improvement in $\mathcal{D}$ was witnessed, the geometry would be altered following the same trend of design change; if an improvement was not obtained, we would try to reverse the direction of design change. If the desired result has been achieved or the improvement could not be obtained after quite a few rounds of iterations, the process would be terminated.

C. Finite Element Model

Each roller has a steel core covered in wear-resistant rubber. First, a compression test was conducted on the physical rollers. A universal compression machine was used to apply 200 kgf on the roller and measured the deformation of it. After that, ANSYS APDL software was employed to establish a three-dimensional model to simulate the compression test. Nonlinear Neo-Hookean material law was assumed in the finite element models; by adjusting the material constant, the same deformation as the measurement was obtained under the same compressive force in the experiment. The equivalent Young's modulus obtained was about 93.5Mpa, which served as the basis for a series of subsequent analyses. The compression analysis was then conducted by rotating the MW at various angles of rollers in the finite element model. The radial displacements of respective angles of rollers were obtained, and the compressive stiffness of the respective angles was estimated and presented as shown in Fig. 2.

Based on the optimization procedures illustrated in Fig. 3, a series of finite element analyses were carried out. Fig. 2 indicated that the rollers needed to reduce the rubber thickness at some positions for enhancement of the local stiffness. This can be done by altering the outer shape of the steel core, which will also change the thickness of the rubber layer at the

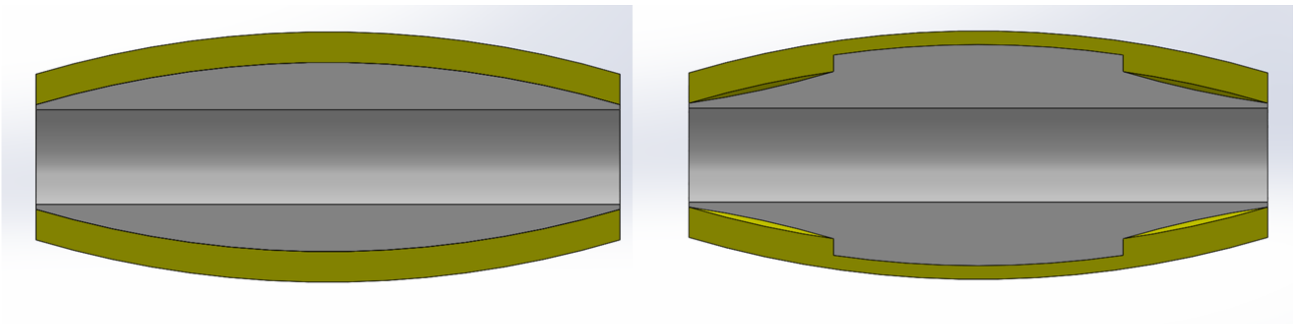

Fig. 5. Cross-sectional designs of the Mecanum Wheel roller before (left) and after modification (right).

location. When two adjacent rollers are transitioning, the finite element model simulates the condition where both rollers contact the ground and share the load. Typical results of the finite element analyses are shown in Fig. 4, which indicate double contact during the transition of rollers. After a series of finite element analyses and adjustments according to the optimization process, the final results in Fig. 5 were obtained.

IV. RESULTS AND DISCUSSION

In this study, the cause of vibration with Mecanum Wheels was investigated; a design change to remedy the problem was proposed. It was found that a high degree of correlation exists between the compressive stiffness of rollers and the thickness of the rubber cover. By changing the shape of the steel core, the rubber thickness of the rollers can be adjusted, while the circumference of the MW remains unchanged. Thus, by modifying the rubber thickness at different locations, the stiffness of the rollers was optimized to be uniform at all angles. As a result, the vibration due to inconsistent wheel stiffness can be mitigated.

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