Modelling of a mecanum wheel taking into account the geometry of road rollers

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Abstract. During the process planning in a company one of the basic factors associated with the production costs is the operation time for particular technological jobs. The operation time consists of time units associated with the machining tasks of a workpiece as well as the time associated with loading and unloading and the transport operations of this workpiece between machining stands. Full automation of manufacturing in industry companies tends to a maximal reduction in machine downtimes, thereby the fixed costs simultaneously decreasing. The new construction of wheeled vehicles, using Mecanum wheels, reduces the transport time of materials and workpieces between machining stands. These vehicles have the ability to simultaneously move in two axes and thus more rapid positioning of the vehicle relative to the machining stand. The Mecanum wheel construction implies placing, around the wheel free rollers that are mounted at an angle 45°, which allow the movement of the vehicle not only in its axis but also perpendicular thereto. The improper selection of the rollers can cause unwanted vertical movement of the vehicle, which may cause difficulty in positioning of the vehicle in relation to the machining stand and the need for stabilisation. Hence the proper design of the free rollers is essential in designing the whole Mecanum wheel construction. It allows avoiding the disadvantageous and unwanted vertical vibrations of a whole vehicle with these wheels. In the article the process of modelling the free rollers, in order to obtain the desired shape of unchanging, horizontal trajectory of the vehicle is presented. This shape depends on the desired diameter of the whole Mecanum wheel, together with the road rollers, and the width of the drive wheel. Another factor related with the curvature of the trajectory shape is the length of the road roller and its diameter decreases depending on the position with respect to its centre. The additional factor, limiting construction of the road rollers, is their bearings. Depending on the load, carried by the vehicle and the rotational speed of the drive wheel, the bearings themselves can greatly affect the diameter of the rollers and the whole Mecanum wheels. The solution of this problem is presented in the paper. It is illustrated with virtual models elaborated in advanced program of the CAE class.

1. Introduction
The wheel Mecanum with rollers that allow the vehicle to move in any direction of the X-Y plane was invented in 1977 by engineer Bengt Ilon. This vehicle was so innovative that patent rights were purchased by the US Navy utilising new capabilities of vehicles based on this technology. Because of the construction of the Mecanum wheel in which the mobile rollers are positioned at an angle of 45° to the wheel, the vehicle could not only rotate in any direction but also move “sideways” in relation to the driving direction. This technology was used to transport heavy components as well as in hard-to-
reach areas, of a small area where maneuverability of classic vehicles was problematic. The technology was redeemed for civilian use in 1997 and the first company which introduced Mecanum vehicles in the logistics processes was the Airtrax one, launching the “Omni-Directional Lift Truck”.

The Mecanum wheels were used by transport vehicles in production processes, by the platforms for educational robots, by chassis of mobile robots and inspection robots and by vehicles for disabled persons (wheelchairs). One of the companies, dealing with robotics that has been interested in Mecanum wheels is the company KUKA, which elaborated the concept vehicle “MOIROS” that is presented in figure 1.

![MOIROS](image)

**Figure 1.** KUKA concept vehicle “MOIROS”.

The mentioned vehicle elaborated by the KUKA firm is a good example of multi-task transport platform elaborated for assisting in production processes. “MOIROS” is a vehicle with a carrying capacity of 8 tons. It moves using the omniMove platform. This platform is equipped with batteries allowing 8 hours of its continuous operation. On the platform was mounted manipulator with a load capacity of 120 kg.

Constant works are conducted on the construction of vehicles with Mecanum wheels. Their results allow expanding the range of possible application of this concept. The Mecanum platforms are increasingly used in new industry branches, but mainly in robotics applications.

2. **Idea**

To make possible the utilisation of a platform based on Mecanum wheels, the special attention should be paid to the accuracy of the entire mechanism [1, 2] as well as to the possible problems arising from the incorrect construction of the Mecanum wheel and the Mecanum rollers itself. Incorrect calculation of the Mecanum roller profile can cause problems with the vehicle positioning in space because of vertical motion which is undesirable. To solve that problem it is possible to use modern engineering environment allowing conducting engineering calculations and parts designing [9, 10].

In this paper is presented the computational process as well as the final result of an exemplary Mecanum roller calculation [3]. The analysis of solutions in the literature, related to the problem of Mecanum wheel designing, do not includes information concerning the proper relations between the diameter of the wheel and the length of the rollers. Similarly there are no any information considered
the equation describing the shape of the Mecanum rollers. The results obtained during the work concerning these two issues are presented below.

![Diagram of Mecanum roller parameters](image)

**Figure 2.** Basic parameters of the Mecanum wheel.

In above figures the particulate symbols determine specific geometric features of designed Mecanum rollers an in particular:
- \( r_{kn} \) – radius of the drive wheel,
- \( r_w \) – radius of the Mecanum roller,
- \( d_w \) – diameter of the Mecanum roller,
- \( \alpha \) – angle of rotation of the drive wheel.

In figure 2, on the right side, a Mecanum wheel, in static position is shown. The dotted circle presents the enveloped determined by the Mecanum wheel which depends both on the radius of the drive wheel and the radius of the Mecanum roller. That diameter of the whole system of the Mecanum wheel could be describe as:

\[ r_c = r_{kn} + d_w \]

The left part of figure 2 shows the triangle formed from the radius of the Mecanum wheel remaining in rest as well as the radius of the wheel after rotation by the angle \( \alpha \). The basic geometric relations are presented below.

\[ \cos \frac{1}{2} \alpha = \frac{h}{r_c} \quad (1) \]

\[ h = \cos \frac{1}{2} \alpha r_c \quad (2) \]

\[ \sin \frac{1}{2} \alpha = \frac{l}{r_c} \quad (3) \]

\[ l = 2r_c \sin \frac{1}{2} \alpha \quad (4) \]

In figure 3 is shown the distance \( h_p \) which is the value by which the radius of the analyses Mecanum roller is reduced, depending on the rotation of the wheel. As it can be seen in figure 3, the angle \( \theta \) is equal to half of the angle \( \alpha \).
Figure 3. Contact point of the Mecanum roller with the base and after rotating by the angle $\alpha$.

Below are presented the equations describing the geometric parameters in figure 3.

\[ \theta = 90^\circ - \beta = \frac{1}{2} \alpha, \]

(5)

\[ \sin \theta = \frac{h_p}{l_w}, \]

(6)

\[ h_p = \sin \delta l, \]

(7)

\[ r_{wp} = r_w - h_p \]

(8)

where:

$r_{wp}$ – radius of the Mecanum roller at the given rotation angle of the drive wheel.

As it is seen from the above relationship, the radius of the Mecanum roller varies depending on the angle of rotation of the drive wheel and its minimum value depends on the $h_p$ parameter.

\[ r_{wp} \geq h_p \]

(9)

Figure 4 shows the position of the Mecanum roller on the drive wheel. By default, in these wheels the angle of the roller is $45^\circ$ degrees.

Figure 4. Placement of the Mecanum roller in relation to the drive wheel.
The basic geometric parameters take values according to equations below:

\[
\cos \delta = \frac{l_w \cos 45^\circ}{l}, \quad (10)
\]

\[
l_w = \frac{l \cos \delta}{\cos 45^\circ} \quad (11)
\]

where \( l \) according to equation (4) is equal to:

\[
l = 2r_d \sin \frac{1}{2} \alpha
\]

From the above relationships it follows that the length of the Mecanum roller depends on the angle of inclination of the Mecanum roller in relation to the drive wheel (in the case above the angle is 45\(^\circ\)), the radius of the drive wheel \( r_{kn} \) as well as the radius of the Mecanum roller \( r_w \).

3. Modelling of the Mecanum wheel

Using the dependencies presented in the article, several computational examples were made to verify the correctness of the elaborated equations. In order to obtain a contour of the Mecanum circle, the dependence could be used linking the Mecanum roller length with its diameter as well as the diameter of the Mecanum roller in relation to the rotation of the drive wheel [4, 5].

A graph showing the outline of the Mecanum wheel at the assumed parameters is presented in figure 5. The following geometric parameters were used to elaborate the outline of this contour:

- radius of the Mecanum wheel \( r_c = 50 \text{ mm} \),
- radius of the Mecanum roller \( r_w = 15 \text{ mm} \).

The CAD model of the Mecanum roller shown in figure 5 was made with the same parameters as the graph shown in the right side of figure 5 [7, 8]. To obtain the exact outline of the roller, the data from the program were imported as points of the spline function.

![Figure 5. Determine outline of the Mecanum roller and its CAD model.](image)

As it could be seen the CAD model has been modified by adding a hole for the axis of the Mecanum roller. Depending on the rotational speed of the roller as well as its weight and the load of the Mecanum wheel the roller shaft could be bearing with the sliding bearing or with rolling one. These constructional features could affect the geometrical shape [9, 10], obtained with the presented equations as well as could limit the total length of the Mecanum roller. The diameter of the bearing bush [11, 12] limits the minimal diameter of the Mecanum roller.
4. Conclusions
The analyses, presented in the article, should make it easy to calculate the improvement shape of the Mecanum roller [6]. Using 3D printers, there is a possibility to use the elaborated models of the Mecanum rollers to print the rollers and hence the whole Mecanum wheel. They could be utilized to build mobile robots as well as inspection ones.

The other problem related with designing Mecanum rollers is the issue of proper material selection. The wear of these rollers is very intensive so it is the need to apply more sophisticated steel like duplex ones [11, 12] or more developed manufacturing technologies. It should be stated that only balanced linking of geometrical and material features could lead to obtaining more improved solution.

5. References
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