Mathematical and graphical modelling of an inertial system that uses the force of inertia of a liquid

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Abstract. In the work is described an inertial system of transforming the rotational movement into unidirectional linear motion using the inertia force of a liquid, which ensures the obtaining of the unidirectional linear motion of the device to which this system is mounted, without the need to achieve a kinematic chain from the drive engine of the system to the running wheels of the device (on which this inertial system is mounted). The system is composed of a cylinder having a cavity, of another full cylinder, some pallets with the possibility of radial sliding, some front sealing caps, components that delimit some variable volumes of liquids during a complete rotation, rotation made with the help of the mentioned pallets, thus leading to the realization of a traction force according to a well-established direction. The paper also presents the mathematical calculation of the inertia force developed by this system during rotation by 360^0.

1. Introduction

In order to achieve the translational movement with the help of inertial systems (i.e., without the need to use a drive chain from the drive engine to the running wheels of the device on which the inertial system is mounted) [1-3], a series of inertial systems are known having remained in patent phases because they have a low efficiency or because the inventors did not take into account the reaction forces that occur in the type of operation [4-7].

2. Description of the system

The modeling is done for an inertial system that is capable, with the help of a liquid driven in rotational motion whose volume in the compartments bounded between cylinders 1 and 2 and pallets 3 varies from a minimum to a maximum during operation thus achieving centrifugal forces of different values in different directions, forces that will have a maximum value according to a well-defined direction, which serves to obtain the unidirectional translational movement of the device on which this system is mounted, as shown in figure 1. The aforementioned liquid was in the volume bounded by the inner cavity of cylinder 2 (whose axis of symmetry is shifted eccentrically with the eccentricity of the e relative to the axis of symmetry of cylinder 1) of cylinder 1 and of the front sealing caps 8.

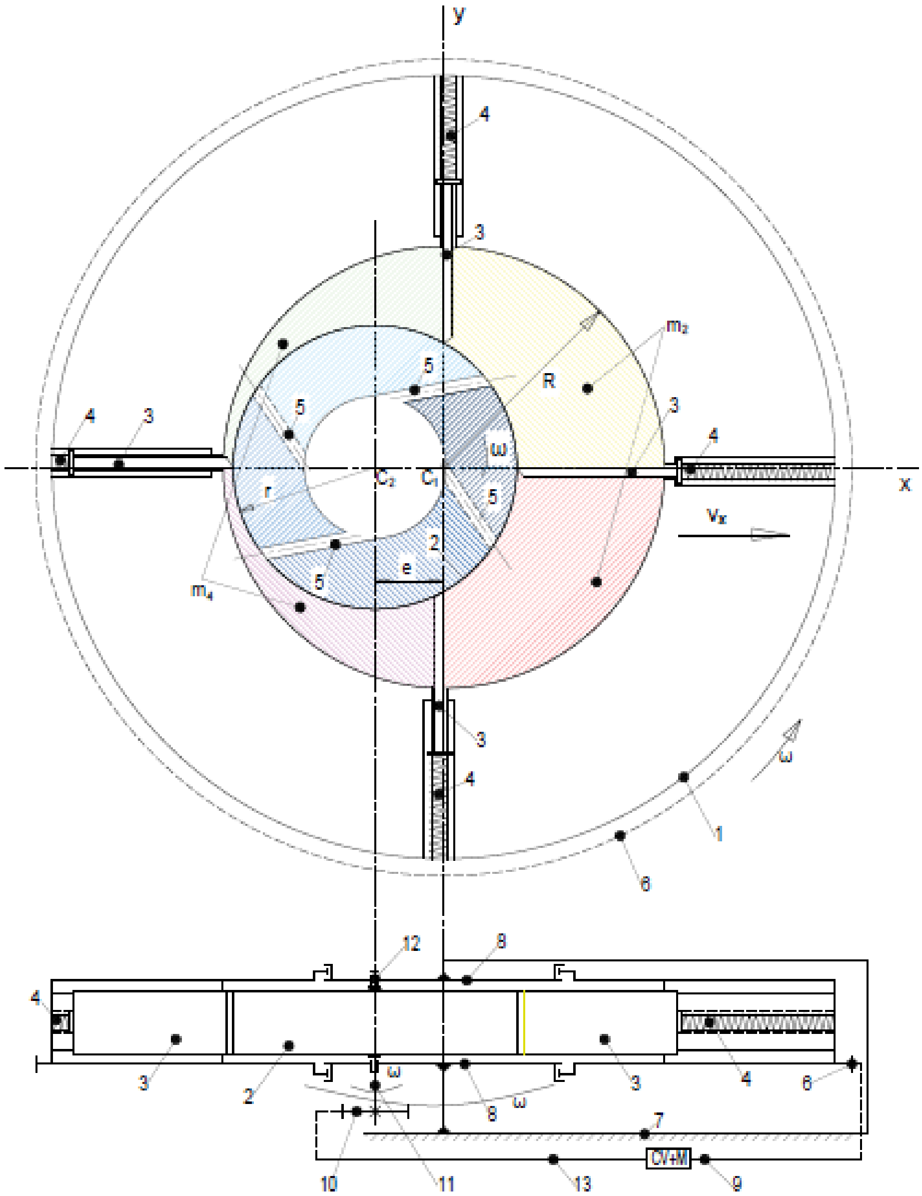

Figure 1. Overview of the inertial system

Where: 1. Outer cylinder, 2. Inner cylinder, 3. Pallets, 4. Helical arc, 5. Channel, 6. Toothed crown, 7. Arm, 8. Fixed bore, 9. Kinematic chain, 10. Gear wheel, 11. Mobile spindle, 12. Mobile ax, 13. Kinematic chain of gearbox and engine drive system and v_x - the speed of the vehicle where the system is mounted, ω represents the angular velocity of the liquid in relation to the coordinates of the center of gravity.

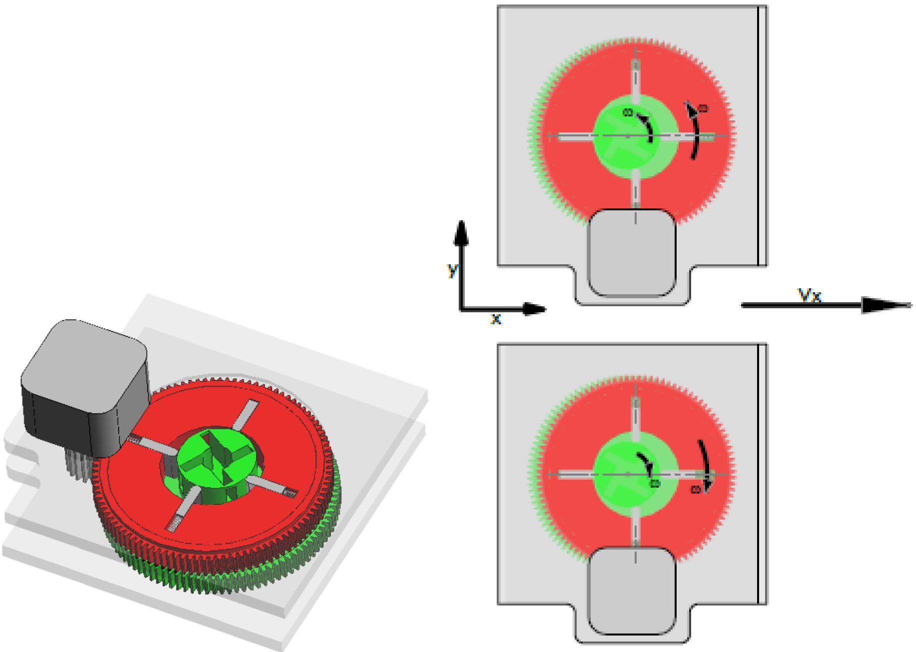

Figure 2. The group of pair of the inertial systems

The driving of the liquid in rotational motion is provided with the help of the 4 pallets 3 mounted at equal angles between them in the body of cylinder 1.

Cylinders 1 and 2 are driven in rotational motion by means of kinematic chain 13 and 9 using the CV gearbox and the M motor. Because in different compartments of the liquid their volume varies, during operation, which is allowed by the circulation of these liquids between diametrically opposed compartments in channels 5. For a better balancing of the system, it is good to double the system according to figure 2.

In order to be able to mathematically deduce the existence of the resultant centrifugal force inequitable with zero after a certain well-established direction we use figure 3, figure 4 and figure 5.

In order to find out the center of gravity of the liquid in the system according to figure 3 we can write the equation of moments relative to the center of gravity C as follows:

$$G_1 x_c = G_2 \left(x_c + e \right) \tag{1}$$

Where:

G_1 - the weight of the volume of liquid corresponding to the cavity in cylinder 1 considering and the gap occupied by cylinder 2 also by the liquid;

G_2 - the weight of the volume of liquid corresponding to the volume occupied by cylinder 2;

x_c - coordinated after the OX axis of the center of gravity of the volume of actual occupied liquid;

e - eccentricity between the centers of the two cylinders 1 and 2.

in other words:

$$m_1 \cdot g \cdot x_c = m_2 \cdot g \cdot \left(x_c + e \right) \tag{2}$$

Where:

m_1 - the mass of the liquid corresponding to the weight - G_1;

m_2 -the mass of the liquid corresponding to the weight - G_2;

g - gravitational acceleration.

further:

$$\rho \cdot V_1 \cdot g \cdot x_c = \rho \cdot V_2 \cdot g \cdot (x_c + e) \tag{3}$$

Where:
V_1 - the volume of the liquid corresponding to the weight - G_1;
V_2 - the volume of the liquid corresponding to the weight - G_2;
ρ - density of the liquid.
Or:

$$dS_l \cdot x_c = dS_g \cdot (x_c + e) \tag{4}$$

Where:
S_l - the cross-sectional area of the cylinder 1;
S_g - the cross-sectional area of the cylinder 2;

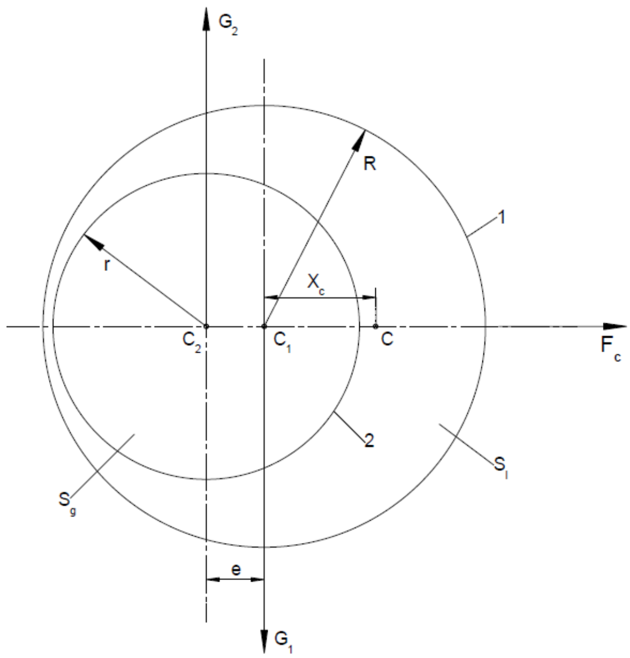

Figure 3. The calculation diagram of the coordinate of the center of gravity of the liquid
Or:

$$\pi \cdot R^2 \cdot x_c \cdot d = \pi \cdot r^2 \cdot (x_c + e) \cdot d \tag{5}$$

Where:
d - the height of cylinders;
R - the radius cavities of cylinder 1;
r - the radius cavities of cylinder 2.
From the formula (5) if we express x_c, results:

$$x_c = \frac{r^2 e}{R^2 - r^2} \tag{6}$$

In this case the centrifugal force can be written in the form of:

$$F_c = (m_1 - m_2) \cdot x_c \cdot \omega^2 \tag{7}$$

the formula in which ω represents the angular velocity of the liquid in relation to the coordinates of the center of gravity x_c.

The formula (7) can also be written in the following forms:

$$F_c = (\rho \cdot v_1 - \rho \cdot v_2) \cdot x_c \cdot \omega^2 \tag{8}$$

Or:

$$F_c = \left(\rho \cdot d \cdot \pi \cdot R^2 - \rho \cdot d \cdot \pi \cdot r^2\right) \frac{r^2 \cdot e}{R^2 - r^2} \cdot \omega^2 \tag{9}$$

and in the end, we get:

$$F_c = \rho \cdot d \cdot \pi \cdot r^2 \cdot e \cdot \omega^2 \tag{10}$$

If we still use the notations in figure 4 where S_i , represents the area corresponding to the number $i \in \{1, 2, ..., 5\}$:

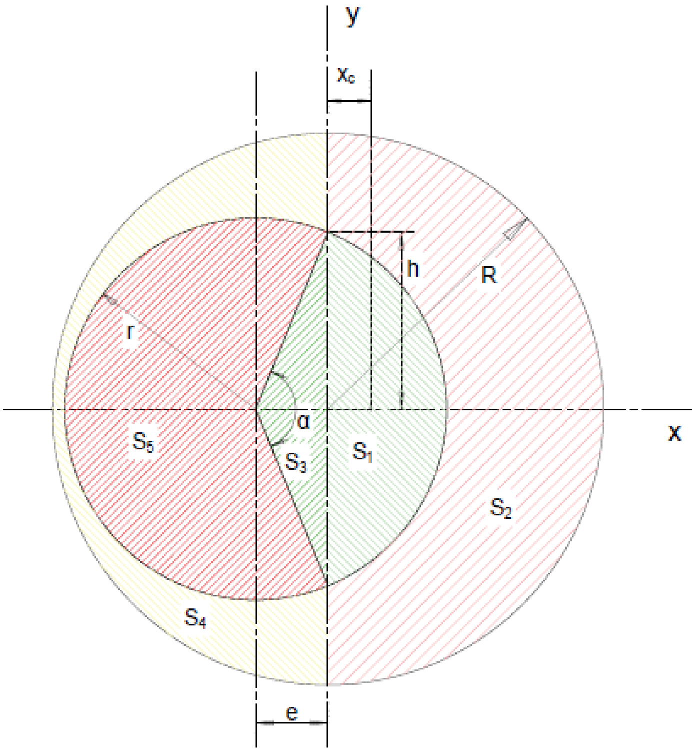

Figure 4. Scheme of the areas of the different portions of liquid delimitation

Where: α - the angle determined by the eccentricity between the two centers of the circles of radius r, respectively R.

$$\cos\frac{\alpha}{2} = \frac{e}{r} \tag{11}$$

from which it results:

$$\alpha = 2 \cdot ar\cos\frac{e}{r} \tag{12}$$

If at 360° match $\pi \cdot r^2$ then at α° match $S_1 + S_3$. From the notations on figure 4, results:

$$h = r \cdot \sin\frac{\alpha}{2} \tag{13}$$

In turn:

$$S_3 = h \cdot e \tag{14}$$

S_3 - the section delimited by the planes forming the angle α and the plane passing through the y-axis.

$$S_1 = \frac{\alpha \cdot \pi \cdot r^2}{360} - S_3 \tag{15}$$

S_1 - the section delimited by a plane passing through the y-axis and the cylinder 2.

$$S_2 = \frac{\pi \cdot R^2}{2} - S_1 \tag{16}$$

S_2 - the section delimited by the plane passing through the y-axis and the right side of the cylinder 1.

$$S_5 = \pi \cdot r^2 - S_3 - S_1 \tag{17}$$

S_5 - the section delimited by the planes forming the angle α and cylinder 2.

$$S_4 = \frac{\pi \cdot R^2}{2} - S_5 - S_3 \tag{18}$$

S_4 - the section delimited by the plane passing through the y-axis and the left side of the cylinder 1.

If we note with m_c the difference in mass divided by 2, corresponding areas $(S_2 - S_4)/2$ we can write:

$$m_c = \frac{S_2 - S_4}{2} \cdot \rho \cdot d \tag{19}$$

and if we look at figure 5, we can see that during such a rotation of cylinders 1 and 2 the amount of mass m_c passes from the portion corresponding to the area $S_2/2$ in the appropriate portion $S_4/2$ diagonally.

If we note the tangential velocities with:

$v_{1\max}$ - the maximum tangential speed in the channel noted by 5 (figure 1),

v_{2r} - the tangential speed in the channel noted by 5 (figure 1) at radius *a*,

Δv_{rmed} - variation of the tangential mean velocity between the rays *r* respectively *a*.

and with Δv_{rx} component by axis OX of Δv_{rmed} we can write the formulas:

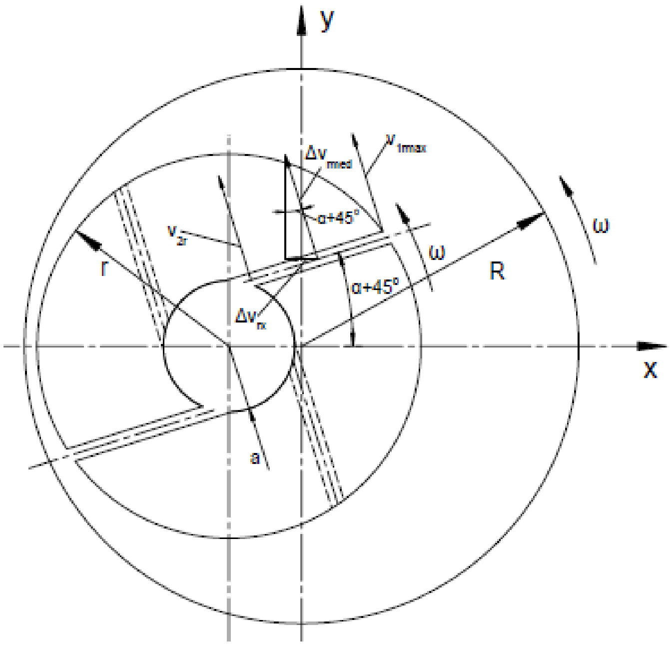

Figure 5. The scheme of the forces produced in the channels of liquid circulation

$$v_{1\max} = \omega \cdot r \tag{20}$$

$$v_{2r} = \omega \cdot a \tag{21}$$

$$\Delta v_{rmed} = \frac{\omega \cdot (r + a)}{2} \tag{22}$$

$$\Delta v_{rx} = \Delta v_{rmed} \cdot \sin(\alpha + 45^{\circ}) \tag{23}$$

In formula (23)

$$\alpha = \omega \cdot t \tag{24}$$

The acceleration according to the OX direction of the coordinate system of the center of gravity of the liquid in each channel noted as 5 on the figure 1 is:

$$a_{1x} = \frac{\Delta v_{rx}}{\Delta t} \tag{25}$$

If at n rotations corresponds to 60s then at 1/4 the rotation corresponds to:

$$\Delta t = \frac{60 \cdot s}{4n} = \frac{15}{n} \tag{26}$$

Replacing the formula (26) in (25) results:

$$a_{1x} = \frac{\Delta v_{rx} \cdot n}{15} \tag{27}$$

And if:

$$n = \frac{60 \cdot \omega}{2\pi} \tag{28}$$

The following shall be substituted in the formula (27):

$$a_{1x} = \frac{\Delta v_{rx} \cdot 60 \cdot \omega}{2\pi \cdot 15} = \frac{2 \cdot \Delta v_{rx} \cdot \omega}{\pi} \tag{29}$$

So, the force that opposes the movement in each channel is:

$$F_{ri} = a_{1x} \cdot \frac{m_c}{2} \tag{30}$$

If we make the appropriate replacements for F_{ri} as follows:

$$m_c = \left(\frac{\pi \cdot R^2}{2} - \frac{S_1}{2} - \frac{\pi \cdot R^2}{2} + \frac{S_5}{2} + \frac{S_3}{2} \right) \cdot \rho \cdot d = \left(S_5 + S_3 - S_1 \right) \cdot \frac{\rho \cdot d}{2} = \left(\pi \cdot r^2 - S_3 - S_1 + S_3 - S_1 \right) \cdot \frac{\rho \cdot d}{2} \tag{31}$$

$$m_c = \left(\pi \cdot r^2 - 2 \cdot S_1 \right) \cdot \frac{\rho \cdot d}{2} = \left(\pi \cdot r^2 - 2 \cdot \frac{\alpha \cdot \pi \cdot r^2}{360} - h \cdot e \right) \cdot \frac{\rho \cdot d}{2} = \left[\pi \cdot r^2 \left(1 - \frac{2 \cdot ar\cos \frac{e}{r}}{90} \right) - h \cdot e \right] \cdot \frac{\rho \cdot d}{2} \tag{32}$$

Get:

$$F_{ri} = \frac{\omega^2 \cdot (r + a) \cdot \sin\left(\omega \cdot t + 45^\circ \right)}{2\pi} \left[\pi \cdot r^2 \left(1 - \frac{2 \cdot ar\cos \frac{e}{r}}{90} \right) - h \cdot e \right] \cdot \rho \cdot d \tag{33}$$

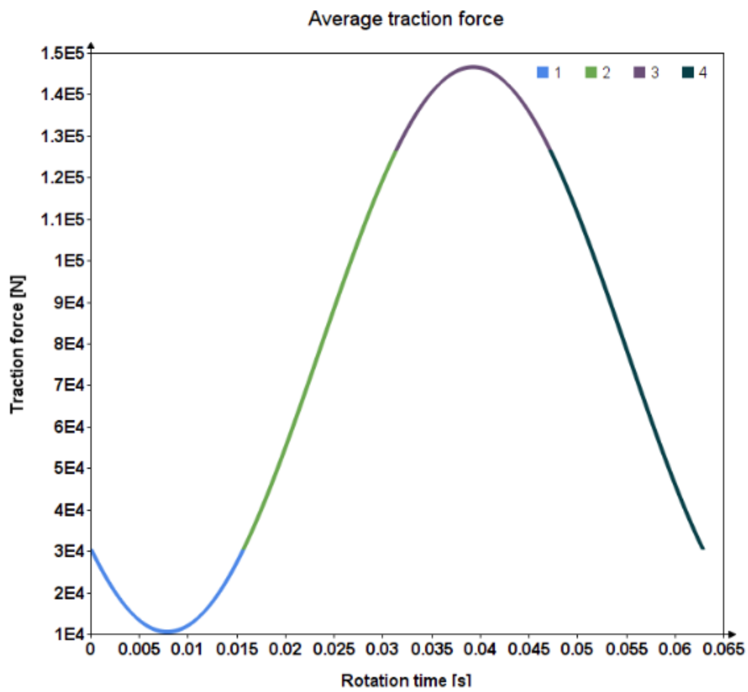

Figure 6. The graph of the average traction force of the system

Where: The value of the opposing force in the channels of liquid circulation corresponding to the rotation 1- α of 0° to 89°, 2- α of 90° to 179°, 3- α of 180° to 269°, 4- α of 270° to 359°.

Using the facilities of MathCAD in a particular case of system parameters we obtain the value of the average traction force of the system according to figure 6.

Subtracting from the formula of the centrifugal force the formula of the opposing forces, the graph in figure 6 is obtained, and according to the calculation of the integral of the difference of forces (equation 34) on the considered time interval, we obtain:

$$\int_0^{2\pi}\left\{(-1)\cdot\frac{\omega^2\cdot(r+a)\sin\left(\omega\cdot t+45^\circ\right)}{2\pi}\left[\pi r^2\left(1-\frac{2ar\cos\frac{e}{r}}{90}\right)-he\right]\rho\cdot d+\rho\cdot d\cdot\pi\cdot r^2\cdot e\cdot\omega^2\right\}dt = \tag{34}$$

$$=4.9348022\cdot 10^5\left[N\cdot s\right]$$

Figure 6 shows the variation of the inertial force during a complete rotation 2π of the device. It is observed that the variation of the force is sinusoidal, varying between $1\cdot 10^4\left[N\right]$ and $1{,}5\cdot 10^5\left[N\right]$. According to the graph it is observed that the inertial force is always positive and of the order of magnitude up to $10^5[N]$ value that justifies the use of the system. The total force impulse developed by this system has value $4.93\cdot 10^5\left[N\cdot s\right]$.

3. Conclusions

The inertial system obtains a traction force after a well-established steering capable of producing the unidirectional displacement of the device on which this system is mounted without the need to use a driveline from this system to the running wheels of the device.

Each element of the mechanism is designed in such a way that it can be done with some known simple machining. It is worth mentioning that the sealing between portions of liquid volume performed with the help of drive pallets does not have to be perfect, being sufficient metal-to-metal seals with rectified contact surfaces.

According to the operating scheme and with the mentions made above, it is possible to conceive and design the practical realization of the mechanical system.

By applying this inertial system, the following advantages are obtained: the realization of a traction force according to a well-established direction with the possibility of modifying the direction of this force by changing the angular position of the eccentricity between the symmetry axes of the cylinders that delimit the liquid, by increasing the speeds of the two cylinders that delimit the liquid, the drive blades ensure an angular speed which is capable of obtaining a relatively high traction force. A main advantage is the simplicity of the component parts that leads to the simplicity of the entire system.

4. Reference

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