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# GEAR MECHANISMS FOR INTEGRAL STEERING OF VEHICLES

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## ABSTRACT
*The paper presents a vehicle with two steering axle, where – for increasing the maneuverability – the rear wheels are turning in the same direction as the front wheels, but with a negative effect on the stability of the vehicle at high speeds. Greater attention was given to achieving “integral steering”: while steering in one direction, the rear wheels to be turned in the same direction as the front wheels – for increasing the vehicle stability – and in the opposite direction – for increasing maneuverability. The paper analyses and proposes cam gears variants for the rear axle steering box, so that whole integral steering requirements are achieved with a purely mechanical system.*
**Keywords:** Cam gear, integral steering, four wheel steering.

## 1. INTRODUCTION

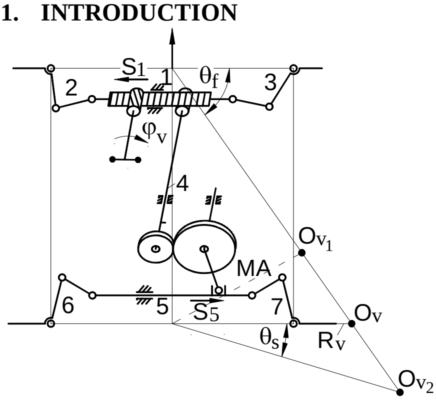



*Figure 1. Classical scheme of integral steering mechanisms with rack/slider.*

For a superior behavior of the vehicle, solutions were searched so that, at high speeds - when vehicle stability is a priority - the rear wheels to be turned in the same direction as the front ones, and as the turning radius is increased, the rear wheels to be aligned, and then to be turned in the opposite direction as the front wheels [3, 4]. This turning of wheels mode have been called “integral steering”.

Thus, at steering in one direction, as the steering wheel angle $\varphi_v$ increases, the turning angle $\theta_f$ will increase continuously corresponding to the wheels of the front axle ($S_1(\varphi_v)$ or $\theta_f(\varphi_v)$). At the same time, considering that at the beginning of steering a vehicle runs at high speed, the rear wheels should turn in the same direction of the front ones, so at first $\theta_s$ is "positive" (Fig. 2). As the $\varphi_v$ and $\theta_f$ increases their values, $\theta_s \to 0$, then it becomes “negative”. Clearly, functions must be identical at steering to left / right, namely for $\varphi_v$ in one way or another.

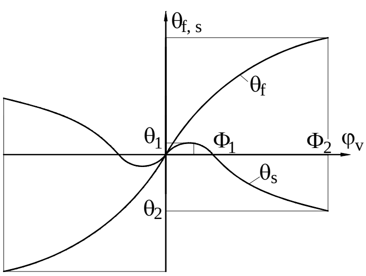



*Figure 2. Kinematical function of “integral steering”.*

For a purely mechanical structure linkages or cams gear (v.fig.1.c) can be adopted, highlighting papers [1], respectively [4], [5] in the functionality proposal / analysis of these mechanical systems.

## 2. CAM GEAR FOR INTEGRAL STEERING

The possibility for cam gears to precisely achieve complex

laws of motion is very high, therefore their use in rear axle steering box is a gain.
Longitudinal shaft 4 (v.fig.1.c) can drive the cams directly from the front axle, and the cams can drive a translational slider or a rotational slider (having the role of a cam follower).
In figure 3, $V_a$ – vehicle speed, I – steering to the right, II – steering to the left. For steering to the right - I, slider 5 positioned in the right side of the cam (fig. 3.a1), in point 1 on the circle with the radius $r_0$ - which marks the position for rectilinear movement of the vehicle. If the cam is rotated clockwise, then, for the rear wheels to pivot first to the direction of the front wheels (to the right), slider 5 needs to move away from the center of the cam, therefore the cam needs a profile 1 – 2 outside of the circle with the radius $r_0$. This is followed by the returning profile 2 – 3 from which the rear wheels can be steered to the left, therefore slider 5 should move to the left, which means a profile 3 – 4 for moving closer to the center of the cam. Thus, the cam profile 1 – 2 – 3 – 4 for steering to the right is obtained.
For steering to the left – II, the cam being rotated counterclockwise, slider 5 needs to move to the left, on profile 1' – 2' followed by the returning profile 2'- 3' (profiles inside the circle with the radius $r_0$); then, the rear wheels are steered in the opposite direction to the front wheels (to the right), which means that slider 5 is moving to the right – following the profile 3' – 4' that is outside the circle with the radius $r_0$. Thus, the profile of the cam 1' – 2' – 3' – 4' for steering to the left is obtained. By connecting the contours 1 – 2 – 3 – 4/1' – 2' – 3' – 4', the complete profile of the cam will be obtained, but indicating that the angle of rotation of the cam in each direction was considered as being 180° and the contact on the profile being on the "right" side.
Under the same conditions of steering I/II and rotation of the cam I/II (clockwise/counterclockwise), but with the cam follower positioned on the "left" side of the cam (fig. 3. a2), by the same reasoning a cam profile is obtained, symmetrical to variant 3,a1 with respect to z-axis, the continuous line showing the profile I/1 – 2 – 3 – 4 for steering to the right and the dotted line showing the profile II/1' – 2' – 3' – 4' for steering to the left.

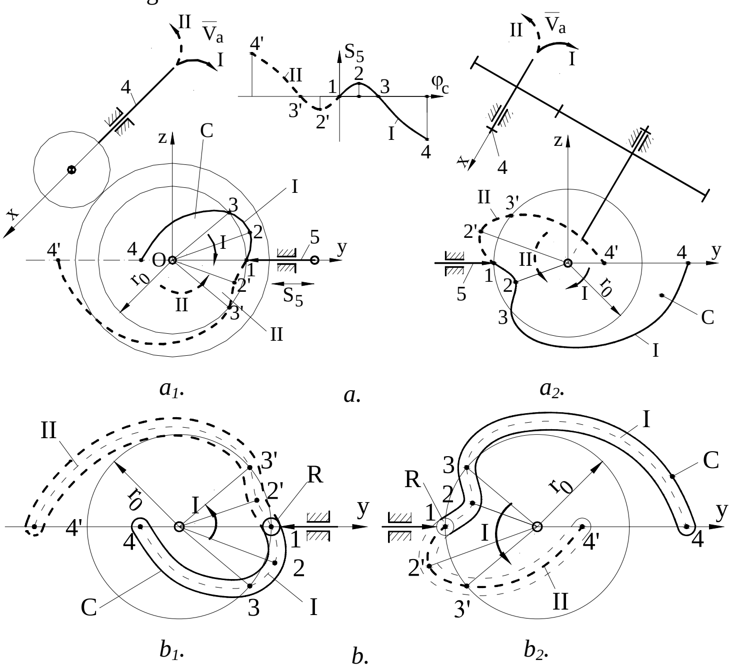


*Figure 3. The arrangement of cam profiles that are rotated by* 180°

In case the rotation of the cam for profile I (steering to the right) is counterclockwise and II clockwise (fig. 3.b), therefore inverse to the previous case, based on the same reasoning, the profile I – II from figures $3.b_1/3.b_2$ is obtained, symmetric to contours in $3.a_1/3.a_2$ in respect to y-axis (slider axis). In diagram 3.b, the roller R was considered as passing through a profile groove of the cam; in diagram 3.a, being a pointed cam follower.
At a rotation $\phi_c$ of cam with 90° in one way or another (so with a full profile of the cam in 180°), the complete profile is shown in figure 4.a, in terms of $3.a_1$ („left" contact, rotation I – clockwise, II – counterclockwise).
Due to the profile symmetry with respect to the z-axis, in case of "left – right" contact, the profile in

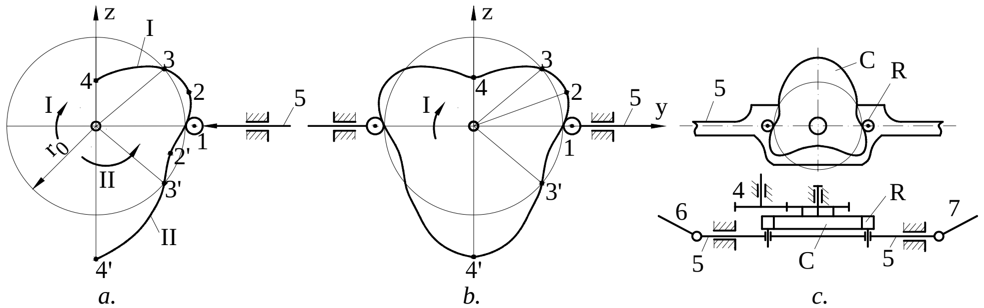



*Figure 4. Arrangement of cam profiles that are rotated by* $90°$

figure 4.a may be completed as shown in figure 4.b, where the two contacts can exist simultaneously, so that the structure can become compact – contact with two rollers, locked cam follower as shown in figure 4.c. The advantage of the structure with two rollers is reduced by the condition of the cam rotation limitation at $\phi_c = 90°$, in one way and the other.

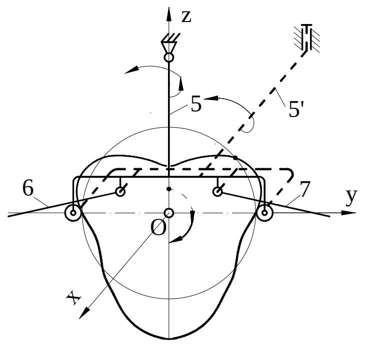



*Figure 5. Cam linkages – floating cam follower for integral steering.*

Such a cam for integral steering may drive not only a translational slider 5, but also a central lever 5 of the rear axle steering mechanism. Central lever can be placed vertically 5 or horizontal 5' (fig.5), driving the steering knuckle rods 6 – 7.

An imposed law for cam profiling can be given directly as a displacement law of the slider cam follower: to the circle with radius $r_0$ a function is added or subtracted – for example the sine on period $0-\pi$ (contour 1 – 3), followed by an addition or subtraction – also a sine function on period $0-\pi/2$ (contour 3 – 4).

Thus, as a *numerical application*, the displacement law is considered (fig. 6)

$$S_{1-3} = a_1 \sin\frac{\pi}{\varphi_a}\varphi_c \text{, respective } S_{3-4} = a_2 \sin\frac{\pi}{2\varphi_b}\varphi_c \text{, with } \varphi_b = \frac{\pi}{2} - \varphi_a \quad ...(1)$$

$\varphi_a$ *- cam rotation angle of the first period , and* $\varphi_b$ *– second period,* $\varphi_c$ – current angle (fig.6).

The following values are considered for the application and the polar radii of the cam are given by:

$r_0 = 40\ mm$, $a_1 = 8\,mm$, $a_2 = 32\,mm$, $\varphi_a = 20°$, $\varphi_b = 70°$.

$r_I = r_0 + S_{1-3}$, respective $r_I = r_0 - S_{3-4}$ for profile I (1 – 2 – 3 – 4); ...(2)

$r_{II} = r_0 - S_{1-3}$, respective $r_{II} = r_0 + S_{3-4}$ for profile II (1 – 2' – 3' – 4').

*Table 1. Numerical calculations.*

| $\varphi_c$ | $0°$ | $5°$ | $10°$ | $15°$ | $20°$ | $10°/30$ | $20°/40$ | $30°/50$ | $40°/60$ | $50°/70$ | $60°/80$ | $70°/90$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $S_{1-3}$ | 0 | 5.65 | 8 | 5.65 | 0 | - | - | - | - | - | - | - |
| $S_{3-4}$ | - | - | - | - | - | 7.10 | 13.85 | 19.93 | 25.08 | 28.83 | 31.20 | 32 |
| $r_{II}$ | 40 | 34.35 | 32 | 34.35 | 40 | 47.10 | 53.85 | 59.93 | 65.08 | 68.83 | 71.2 | 72 |
| $r_I$ | 40 | 45.65 | 48 | 45.65 | 40 | 32.90 | 26.15 | 20.07 | 14.92 | 11.17 | 8.80 | 8 |

The cam representation – for the cam follower with two rollers and $\phi_c = 90°$ in one direction and the other is given in figure 7.a.

For the cam follower with a single roller, accepting $\phi_c = 180°$ in one direction and the other, the cam in figure 7.b is obtained, angle cycles being doubled if compared to previous case, $\varphi_a = 40°$,

$\varphi_b = 140°$, the rest of the data remaining the same, as well as the resulting values (at angles $\varphi_c$ equal with $0, 10°, 20°, 30, 40°$ and $20°/60, 40°/80, 60°/100, 80°/120, 100°/140, 120°/160, 140°/180$).

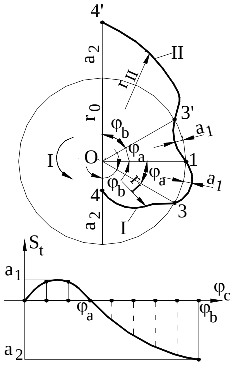
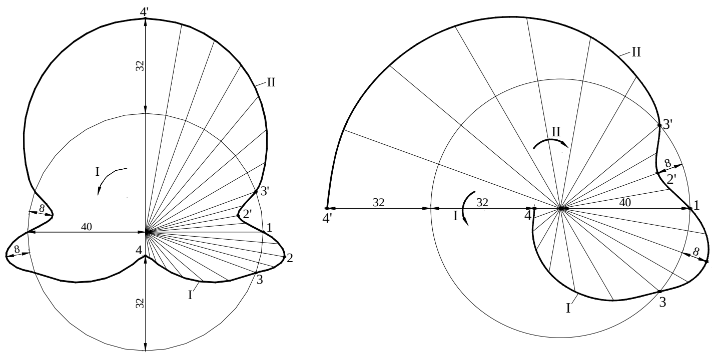



*Figure 6. Movement phases of the cam.*

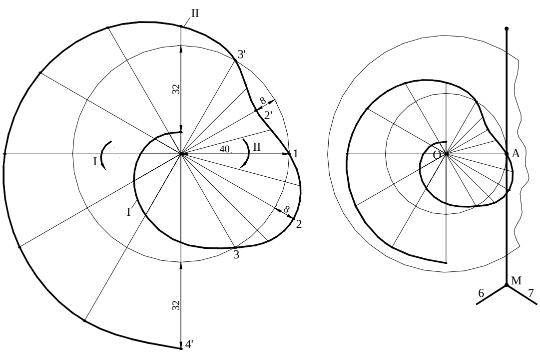



*a.* *b.*

*Figure 7. Numerical application for the cam profile.*

The numerical data entries $a_1 / a_2$, $\varphi_a / \varphi_b$ are intentionally exaggerated for clear stand out of cam profiles. The advantage of cam with a single roller may be found in figure 8.a, to which were considered periods of angles $\varphi_a = 60°$ and $\varphi_b = 210°$; i.e. the maximum cam rotation $\phi_c = 270°$ (discrete angles of cam $\varphi_c = 0, 15°, 30°, 45°, 60°; 30°/90, 60°/120, 90°/150, 120°/180, 150°/210, 180°/240, 210°/270$).

For achieve relatively large stokes $S_5$, amplitudes $a_1 / a_2$ must also be large, which can be inconvenient. In case of cam with a single roller there is a possibility where this is positioned on a rocker 5 (fig.8.b), so that the driving point M of the rocker 6/7 from the mechanism have a multiplied stroke with the arms ratio.




*a.* *b.*

*Figure 8. Cam profiling with $\phi_c = 270°$, respectively rocker driving.*

## 3. CONCLUSIONS

The cam profile is determined by the imposed law, but also by its direction of rotation and maximum angle rotation.

The cam with the framed cam follower, with two contact point's concomitant on left/right profile, is formed a cam with a symmetrical profile, but accepting only a rotation of $90°$ in one way and in the other.

The cam with a single roller can have a rotation angle up to $360°$ in one direction or another.

The cam with a single roller can be linked with a rocker for increasing the driving strokes of the turning of the wheels.

## 4. ACKNOWLEDGMENT

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## 5. REFERENCES

[1] Alexandru, P., Alexandru, C. Mechanisms for the integral steering. 12th EAEC, pg. 99, Bratislava, 2009.
[2] Berkefeld, V., Seifort, G. Four Wheel steering – handling and disturbance compensation on surface with varius fricions conditions. SAE Papers, no. 925051.
[3] Galtier, L. Rear-steering control device for automotive vehicle. U.S. Patent, no. 4.993.730.
[4] Kido, L Steering mechanism for vehicle rear wheels. U.S. Patent, no. 4.943.074.
[5] Sano, S. Steering apparatus for vehicles. U.S. Patent, no. 4.295.657.