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Nonlinear Trajectories Of Invisible Hinge

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Abstract **--Among many different solutions of the door hinges the most engaging is so called invisible hinge with five axis motions. These hinges are perfect for applications where a flush fit, smooth operation, and a compact size are necessary features, as well as being concealed from view. Moreover they provide the highest level of security, because when the door is in the closed position, the hinge cannot be accessed or tampered. But the problem is the following: in the wold-wide market are available from many constructors the hinges with five axis motions which reproduce conceptually only one type of motion path, or in other words, which have practically the same trajectory. This happens due to the absence of fundamental knowledge of hinge kinematic. In our previous article we have analyzed the kinematics and defined the constructive and geometrical parameters, which determine the movement of invisible hinge. In this study we have upgraded previous study and developed a simple geometrical approach to control the trajectory of the hinge by changing the shape and position of sliding guides. In particular, we have proposed the technique for construction the required trajectory of hinges, primarily by means of implementation of nonlinear sliding guides.**

Keywords-- invisible hinge; hinge kinematics; hinge trajectories; external door hinge; full opening door.

I. INTRODUCTION.

Invisible hinges with with five axis motions have been invented in the initial of 20-century and appears initially in the patent of Joseph Soss [1]. This hinge substantially composed from two brackets, connected to each others in the central axis, as much as a pair of scissors. One extreme part of first bracket connected the axis fixed on the frame, another extreme part connected to the moving axis, which is engaged in the sliding guide of the door leaf. The second bracket is connected in the same manner, but with mirror symmetry with respect to the central plain. So, the hinge has 3 fixed axes and two movable axes, which sliding along the proper guide lines. The configuration oh the hinge doesn't changes significantly up to the present days. In the Fig.1 is shown the invisible hinges of Soss-type with five axes of rotation, which recently in production.

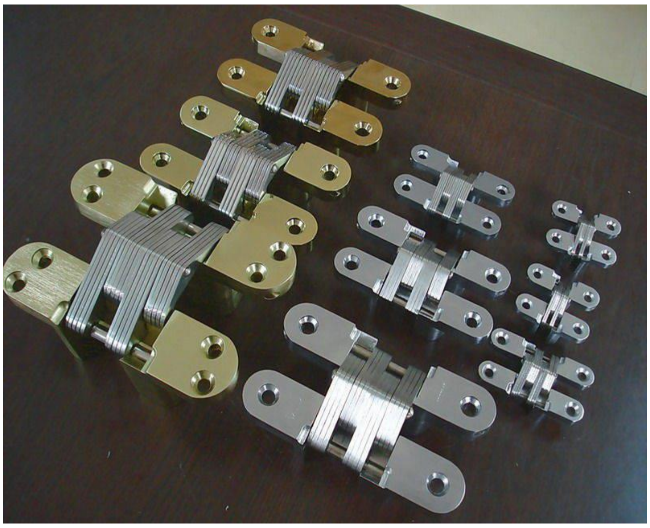

Fig. 1. Example of five-axes Soss-type invisible hinge. The length of the hinges varies from approximately 60 mm to 130 mm.

These hinges are widely used now and than extend out to swing the door up and over chassis frame. This forms match more solid connection with less hinge play then a concealed hinge. There are also specific construction of invisible hinge that are designed to fit either metal or wood cabinetry. The main advantages features are, as describe for example in [2]:

- Aesthetics - When closed, hinge cannot be seen. When open, hinge appears compact and elegant. Allowed flat design, flush with the wall and, at the same time, door swings completely around up to 180°, allowing full unobstructed access to the room or cabinet contents.

- Security - When the door is in the closed position, the hinge cannot be accessed or tampered. Even in the open position, the exposed riveted pin is not removable.

- Safety - The moving pivot point remains inside the hinge during travel until fully opened, eliminating an external pinch point on the back side of the door.

- Unique Motion Path - Motion path is non-circular and swings away from the cabinet, allowing for tight door clearance.

But the Soss-type invisible hinge has an evident disadvantage: the door when closing, can't compressing the double gasket on the hinge side of the door. So, for these hinges only one gasket can be applied. This fact highly limited the use of invisible hinges for external doors, and for the doors requiring effective thermal and acoustic barrier.

It have been proposed some solutions in order to overcome this weakness. In [3] is presented solution when one bracket of the hinge is not fixed to sliding axis rod, so this bracket is fixed only to the central axis rod and two extremes of bracket sliding in corresponding guide lines. Therefore, this design is not a five-axis invisible hinge, as it generally defined. In this construction of hinge one bracket hasn't unique trajectory and therefore when operate, rubbing the surfaces of the guide lines and, as a consequence, can jamming the hinge movement.

Another hinge design, which allows application of the two gaskets between frame and door leaf, was proposed in [4]. In comparison with Soss construction, this hinge has asymmetric brackets and different inclination of the guide lines. But in this case the door panel can not be set flush with the plane of the face of the wall, as shown in the Fig.2.

The “door – wall flush” setting, which allows mounting the thick wall panel, was implemented in the hinge design described in [5]. It have been changed the guide line trajectories and the brackets lengths ratio, see Fig.3. But become again impossible to have two gaskets betwixt the door and the frame.

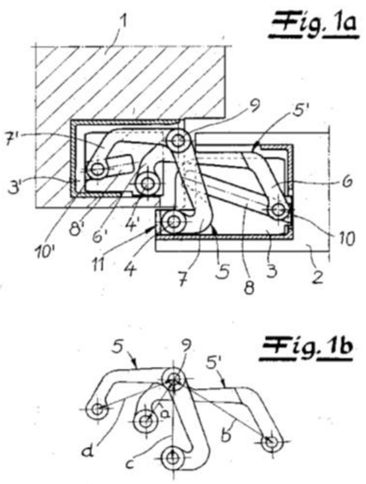

Fig.2. Five axes hinge design which enable setting two gaskets [4].

One design of the invisible hinge, which succeeds to combine the two features: the flush setting with wall and two gaskets mountings between the wall and the frame, was done by Walter Way in the distant 1937 year [6]. In yours symmetric hinge the guide lines have the curved form, it allows to change the direction of sliding axes during movement and as a consequence modify the door trajectory from rotational at the beginning, up to quasi linear at the end of the door closing path. This prominent hinge was created by W. Way using a pure empirical method, as can be understood from the description of his patent [6]. Below we discuss in more detail its configuration, based on knowledge of how the shape and position of the sliding guides can control the trajectory of the hinges.

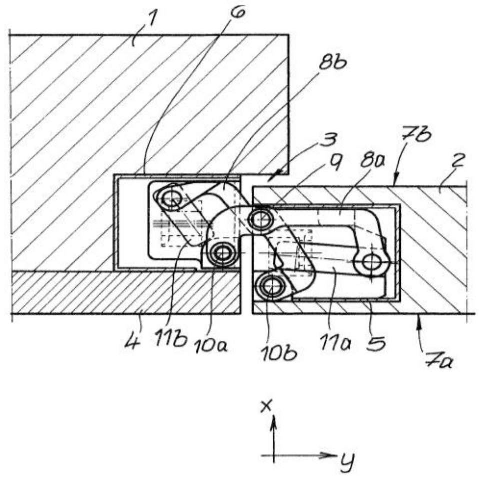

Fig.3. Invisible hinge design allows the door to be flush with the thick wall panel, see [5]

II. DESCRIPTION OF KINEMATIC APPROACH.

In a previous article [8] we developed the analytical approach on the base of trigonometric kinematics, which describes the behavior of the hinge with changing its constructive parameters. We will now discuss some important details that have received little attention or that have been omitted.

By applying the Gruebler's equation [7] to the configuration of invisible hinge with five axes motions, represented in the Fig. 4, we can find the degree of freedom: there are four numbers of links (n) and 5 numbers of joints, namely, 3 joints with 1 degree of freedom (rotation only) and 2 joints with 2 degrees of freedom (sliding and rotation). So, the degree of freedom of overall system can be find as:

$$F = 3*(n - 1) – 3*2 – 2*1 = 1$$

And we can say that the five-axis hinge mechanism, shown in Fig. 4, has a unique trajectory of movement.

This layout can not be considered as a classic slider-crank mechanism, nor as part of it, since the slider guide is integrated into the body of the crank itself. This configuration is more complex than the slider-crank and requires a different approach for analysis. Let us consider the conceptual scheme of the hinge in detail.

As shown in the Fig.4, there are 2 brackets which are joint centrally between each others in the point A. One end of the first bracket is hinged on the axis, fixed on the frame (point P), but another end is engaged in the sliding guide of the door leaf. In its turn, one end of the second bracket hinged on the axis, fixed on the door leaf and another end (point N) correspondingly engaged in the sliding guide of the frame.

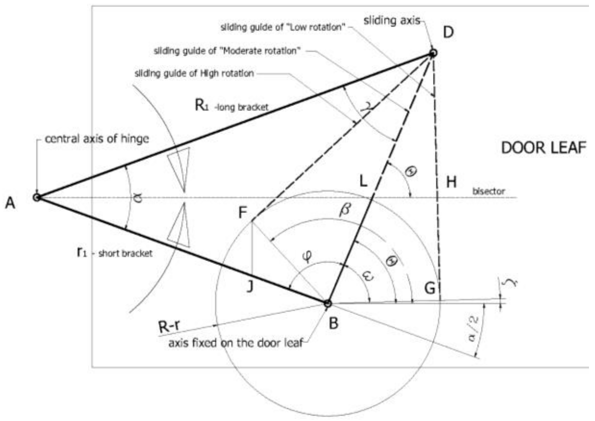

Fig.4 A. Presentation of the part of invisible hinge which belongs to the door. Point A is a center of polar coordinate.

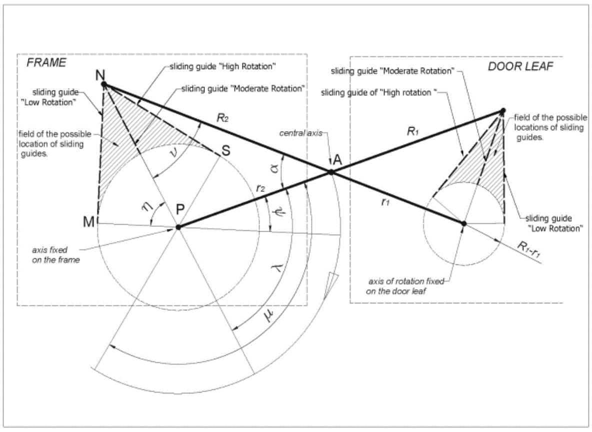

Fig.4 B. Schematic presentation of complete 5-axis invisible hinge.

We named R_1 and r_1 the semi-brackets which responsible for the rotation of the door leaf, as well R_2 and r_2 are semi-brackets which responsible of the rotation of the central joint A with respect to the door frame. We suppose that a frame is fixed and, consequently, point P does not move. In this scheme is shown the general case, that is, all these four brackets can have any length, but with the following constrains: $r_1 < R_1$, and $r_2 < R_2$, otherwise it will change the direction of rotation. The fundamental concept of the discussed approach is the determination of the permissible region of the position of the sliding guides due to geometric constraints. As shown in the Fig.4, this region is delimited between the circle of radius equal to (R-r) around each fixed axis of the hinge and two tangent lines, which go out from start point of the long bracket. Moreover, it was find that, if sliding guide coincide to the external tangent line, than it result in minimum rotation of the door leaf. Otherwise, when the sliding guide coincide to the internal tangent line, this lead to the maximum rotation, or "high rotation" as named in [8], of the door leaf. Any other position of linear sliding guide into the permissible field result in intermediate rotation between these two extremes.

Due to this result, it becomes possible to calculate the maximum rotation angle that reaches the hinge and, also, to determine the angle of rotation as a function of position of sliding guides, the relative length of brackets (R/r) and a starting angle between brackets. For example, as shown in [8], the maximum rotation angle that occurs when both sliding guides pass along the "high rotation" lines, can be expressed in a generalized form as follows:

$$\beta+\mu'=\alpha+\sum_{i=1}^{2}(v_i+\eta_i) \qquad (1)$$

where: β + μ' is the sum of maximum rotation angles of the door and frame parts, see Fig.4A and 4B, taken from equations (1) and (9) of our previous study [8], respectively.

$$v_i=\arcsin[k_i\cdot\sin(\alpha)/g(k_i,\alpha)]$$

$$\eta_i=\arccos[g^{-1}(k_i,\alpha)]$$

And where [8]:

$g(k_i,\alpha) = [k_i^2+(1+k_i)^2-2*(1+k_i)*k_i*\cos(\alpha)]$, $k_i= r_i/(R_i-r_i)$

i = 1,2 - for the first and second semi-brackets of the door and frame parts, respectively.

Expression (1) is presented in the Fig.5 as a graph of the hinge rotation angle vs starting angle between brackets. That is, when the hinge (or door) begins to open, the angle between the brackets decreases, reaching a certain final angle. This final angle has been set to zero, as well as in equation (1).

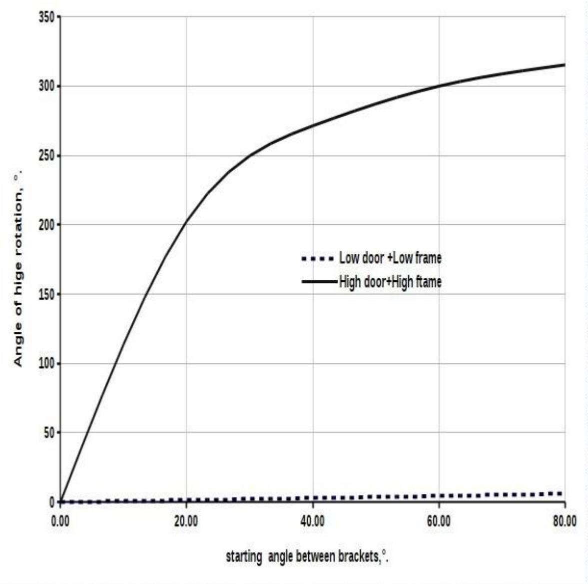

Fig.5. Angle of rotation of symmetrical hinge vs starting angle "α" between brackets, R1=R2, r1=r2 and k =3. "Low door+ Low frame" and "High door+ High frame" mean that sliding guides of the door part and of the frame part are coincide with "low rotation" and "high rotation" lines, correspondingly, see Fig. 4. Final angle "α" is equal to zero.

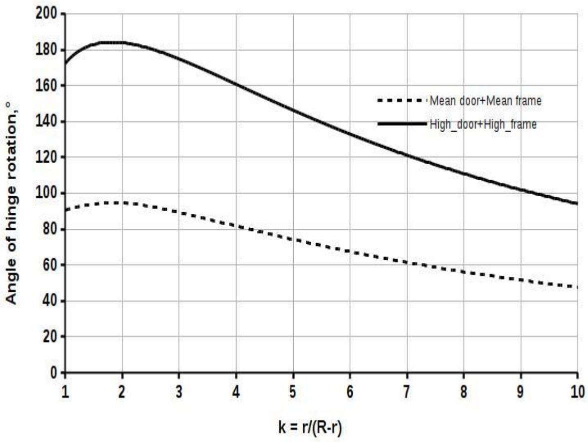

Fig.6. Angle of rotation of symmetrical hinge vs brackets ratio k=r /(R-r). Starting angle between brackets is equal to 60°, but final angle is set to10°.

Also, for comparison, in the same graph is plotted the angle of the hinge rotation vs brackets ratio when the both sliding guides (the frame part and door part) passed along the lines of “low rotation”. So, it should noted, that in one case the hinge rotation angle can can reach up to 300 ° and more. In the other case, at the same conditions, the rotation angle changes slowly, staying almost at zero, despite the increase in the initial angle between the brackets. This means that the position and direction of sliding guides play a dominant role in determining the value of the rotation angle and trajectory of the hinge.

Another important result of the above kinematic approach is presented in the Fig.6, where is plotted also the angle of rotation of the hinge vs the bracket ratio k=r /(R-r). However in this case the final angle between brackets is equal to 10°. As can be see, when the final angle between brackets is not arrives to 0, the graph reaches the maximum at some value of k, which depends on that final angle, and reduces with increasing the value of k. This means that for the real configurations of the hinge, when, as a rule, the final angle is about 5-10 °, the optimal ratio between brackets should be about k = 1□3 and not more than 4 due to a significant reduction in the angle of rotation.

Using this approach we can perform a brief analysis of some existing invisible hinge designs. Due to the fact that, in general, the drawings of the hinge examples do not report the dimensions in absolute units, we will normalize all the dimensions, without loss of generality, by setting the length of the short bracket equal to 1.

Let us look at the drawing presented in Fig.2. This is the hinge patented by Neukötter [4]. First, consider the door part of the hinge. The ratio R/r = 1,48, and k=1,94, so the brackets ratio was chosen properly. The inclination of the sliding guide is directed to the side of the "high rotation" and, as can be estimated from the drawing, coincides approximately with a line tangent to the circle of the radius equal to 0.51. So, the door part of the hinge has optimal configuration. For the frame part we have: R/r = 1,6 and k=1,67. The angle of inclination of the sliding guide relative to the line between the central and fixed axes, estimated according to the drawing, is approximately 25 °. But the angle φ of the tangent line to the circle of radius R-r = 0,6 , can be find as:

$$\varphi \approx \arcsin((R-r)/L) = 40°$$

where L= 0,94 is the distance between central and fixed axes

Therefore, the frame part was not designed in the best way, since the sliding guide is far from the tangent line of "high rotation". Because the coincidence with “high rotation” line allows a more compact design, for example, due to a decrease in the total stroke of the angle between the brackets.

Look at another hinge configuration from [5], shown in Fig.3. For the door part we have: R/r=1,52, which correspond to k= 1,91, and L=1.31. The slope of the sliding guide is oriented in the right direction, but does not reach the slope of the tangent line, which can be calculated, as in previous example, φ ≈ arcsin((R-r)/L) = 23°. With regard to the frame part, in spite of good brackets ratio, that is R/r=1,7, the sliding guide obviously coincides with the "moderate rotation" line, as shown in Fig 4. Therefore, such an invisible hinge design is not the optimal solution from the point of view when it is necessary to obtain the maximum rotation angle of the door with a minimum movement of the hinge or, in other words, with a minimum stroke of the angle between the brackets of the hinge.

In fig. 7 shows the hinge mechanism that was used to handle the Apple notebook cover. You can see, this is the same five-axis hinge with two sliding guides. Both sliding guides are linear and only slightly inclined in the direction of “high rotation”. So, it is not a best possible configuration. The necessary movement of the cover with respect to the base could be more pronounced if, for example, the sliding guides exactly coincide with the tangent lines, as shown in Fig. 4.

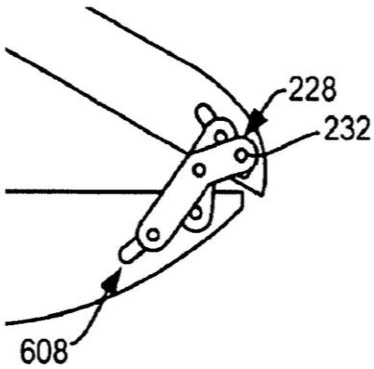

Fig. 7.Application of five axes motion hinge mechanism for Apple notebook cover. See reference [9].

Therefore, as shown above, this approach provides a simple and powerful tool for analyzing various configurations of the invisible cycle, even at the initial stage of the project, and helps to find the best possible solutions.

III. TECHNIQUE TO CREATE THE NONLINEAR TRAJECTORIES OF THE HINGE.

It can be noted that in our previous study we have considered the sliding guides only as the straight lines. But they can be curved and also can have any other shape in the form of an arc or, for example, a zigzag. It is necessary anyway, that a final point of sliding guides must meet with the circumference of radius equal to (R-r), traced around the fixed axis of door or frame parts respectively, due to the geometrical constrains, see the Fig.4. The appearance of possible points of singularity that can occur, for example, when the direction of the driving force vector is orthogonal to the sliding guide, must also be prevented [10].

In the Fig.8 is shown an example of the five-axes invisible hinge with non–linear sliding guides. The trajectories of guides can have any direction and shape, but must finish on the circumference with radius equal to R-r, as indicated in the figure. It should be noted that this geometric composition offers an essential opportunity to graphically calculate the rotation angles independently, for the part of the frame and the part of the door. The angle of rotation is taken between continuous line, traced from central to fixed axis, and point of intersection of sliding guide with circumference R-r, as explicitly shown in the Fig. 8, “β” is rotation angle of the door part, “μ’” is rotation angle of the frame part, correspondingly. Both these angles can be estimated also analytically by using the formulations (1).

The sliding guides of the door part and frame part have been drawn almost deliberately, however with the inverse curvature with respect to the central axis. In this way, as regards the door part of the hinge, an initial portion of the sliding guide goes along the "low rotation" line, and subsequently changes the slope in the "high rotation" direction. On the other hand, the sliding track of the frame part has inverse trajectory, namely, initially has a slope of "high rotation" and ends with a "low rotation". These sliding trajectories result in very specific behavior of the hinge, in particularly, at the beginning of door opening, the central axis moves quickly with decreasing the angle “α” between brackets, but at the same time, the door almost doesn't rotates regarding to the central axis. This lead, at the beginning of the door opening, to linear translation of the door without rotation. And then, with decreasing the angle "α", both sliding guides change direction of movement, therefore the central axis practically does not move, only the rotation of the door occurs.

It should be noted that this type of trajectory of the door provided with two following very useful features. First, the panel (or door), in spite of the flush setting with the wall, can be opened completely up to 180°. And second, the linear translation the door at the end of closing allows to compress both, external and internal gaskets, thereby giving an essential property to the invisible hinge. For this reason such hinge configuration is excellent for exterior doors and shutters, due to the effective breaking of the “thermal bridge” between the outside and inside of the house.

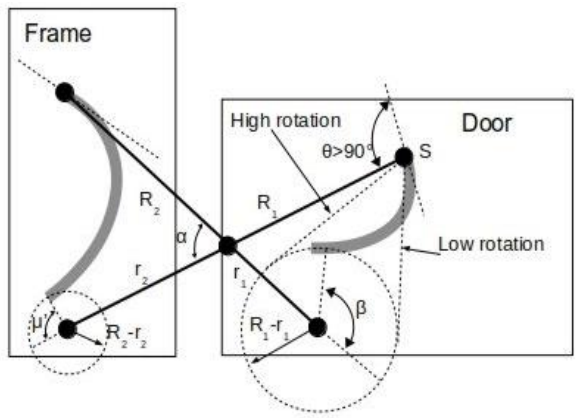

Fig.8. An example of the invisible hinge with curved sliding guide.

Another important thing to consider when creating nonlinear sliding guides trajectories is control of singularity points. As can be seen from Fig. 8, the starting point of the sliding guide of the door portion, indicated by the letter S, is close to the singularity point. The angle “θ” between the tangent line to the guide trajectory and the bracket R1 is slightly higher than 90°. At singularity the cos θ = 0 and the force applied in the direction of the bracket R1 cannot produce any movement.

Let us apply this techniques to analyze a some of existing configurations of hinge having a nonlinear shape of sliding guides.

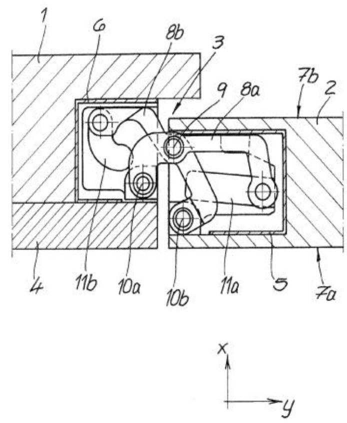

Fig.9. Design of invisible hinge with nonlinear sliding guide, from U.S. Patent No.8,850,661 B2 [5].

In the Fig.9 shows the layout of hinge with nonlinear sliding guide which is presented only on the frame part. In that case the curved sliding guide is directed to "low rotation", and then changes direction to "high rotation". When the slider goes along the first portion of curve, the central axis has low displacement and in such manner cannot provides sufficient space for door rotation. Then slider moves along the final portion of the curve in the “high rotation” direction and thereby recover the overall span of the central axis, as it takes place in the case of linear sliding guide, shown in the Fig. 3. Hence, this curved trajectory don't provide any benefits, with respect to linear one, which is presented in the Fig.3.

Another hinge design with curved sliding guides is presented in the Fig.10. The invention was developed for doors, openable panels and other closures set with the plane of the face of the panel flush with the plane of the face of the wall [6]. Three consecutive opening positions of the panel are shown in Fig.10. As you can see, the initial and central portions of the sliding guides are similar to those presented in Fig. 8. So, at the beginning there is a practically linear displacement of the panel (first opening position in Fig.10), because the slider of the part of the frame moves on the "high rotation" part of the guide, while the slider of the part of the panel goes along the "low rotation" part of the guide. And consequently (the second and third opening positions in FIG. 10), the central axis moves slightly, while the panel rotates at the large angle.

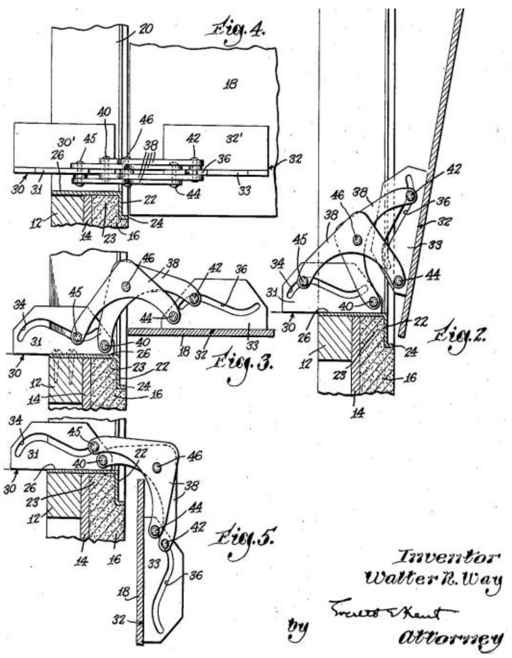

Fig.10. Concealed hinge design with curved guides developed by Way [6].

Therefore this trajectory of sliding guides allow the panel to be flush with the wall in a closed position and at the same time completely open up to 180 °.

In spite of the similar behavior of the our example of the hinge, presented in the Fig. 8 and the hinge invented by Way (Fig.10), the terminal portions of sliding guides slightly differ. In the frame part of Way’s hinge the terminal part of the curve change direction again in the “high rotation” direction, but in the door part the direction changes from “high” to “medium”. But, if we look carefully at the drawing, the positions of the curves of the part of the frame and the part of the door are not identical with respect to the fixed axes, and the sliding path of the door part cannot be terminated in "high rotation" due to geometric constraints. For this reason, the inventor was forced to finish the curve, again changing direction. It should be mentioned that trajectories of sliding guides has been found by Way in a purely empirical manner by selection between a lot of different acceptable curves.

IV. CONCLUSION.

By applying the trigonometric approach, developed in our previous study [8], we shown that a dominant contribution in variation of hinge trajectory provides the shape and position of sliding guides. We have analyzed some existing designs of invisible hinge, having linear sliding guides, shown the drawbacks of these designs and a possible ways to improving.

We have upgraded above approach, by including into consideration the hinges, having nonlinear sliding tracks. We have demonstrated how to control the hinge trajectory by means of changing direction and position of sliding tracks. Also it was developed a graphical and analytical method that allows to calculate the rotation angles of frame portion and door portion of the hinge independently of each other. On the base of this knowledge it was created the hinge configuration, having specific trajectory, namely the linear displacement of the door at the beginning of opening and pure rotation at the end. Due to this trajectory, the hinge perfectly suitable to be use for the external doors and closures, because the door compress two gaskets, external and internal together, while closing. This hinge design is patented, and its detailed description is available in [11]. Finally, the presented approach was applied to existing hinge configurations with non-linear sliding guides in order to analyze the efficiency of the resulting trajectories.

ACKNOWLEDGMENT.

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