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Classification of Reconfigurable Parallel Mechanisms

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Abstract—The theoretically possible reconfigurable parallel mechanisms are classified, in terms of the layout of guides on the base. Formulas are derived for the characteristic parameters of each type. On that basis, individual calculation templates are developed for formalized design of reconfigurable parallel mechanisms.

Keywords: parallel mechanisms, classification, guide layout, reconfiguration

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Today, parallel mechanisms with different numbers of degrees of freedom are widely used in systems such as metal-cutting machines and robots. These mechanisms consist of an immobile element (the base) and a mobile platform (the functional component), connected to the base by several (2–6) kinematic chains [1].

Parallel mechanisms permit high precision in positioning and maneuverability of the machine tool's key components: the spindle chuck or the table. However, a deficiency of such machine tools is that the working space is smaller than for traditional serial kinematics.

Such mechanisms may be improved by permitting reconfiguration [2, 3]. In other words, to enlarge the working space, the configuration is adjusted by increasing the degrees of freedom.

In Fig. 1, we show an example of a reconfigurable machine tool with rods of fixed length, based on a triglide mechanism [2].

Reconfiguration of mechanisms with rods of fixed length involves adjustment of the guide inclination and hence the direction of carriage motion.

The guides of a machine tool may be positioned vertically, with support by a column (Fig. 1a); at an incline (Fig. 1b); and horizontally, with support on the radial brace of the frame (Fig. 1c).

A hexapod machine tool is an example of a reconfigurable mechanism with rods of variable length (Fig. 2) [2].

The workpiece is placed on table *2*. The working element *4* on mobile platform *3* is advanced by simultaneous change in length of rods *5*. The system is reconfigured by displacement of the hinges *6* of the drive rods along the guides *7* on immobile platform *1*. Displacement of the hinges along the guides changes the base radius and hence the shape and size of the working space.

Design of the parallel mechanism entails determination of the angles of the hinges on the base and mobile platform, the length of the drive rods, and other geometric parameters. In the design of a reconfigurable parallel mechanism, we must also determine the length of the guides, their layout on the base, and the distance between them.

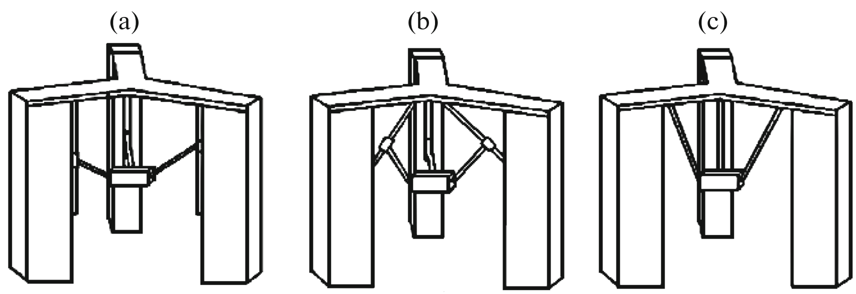

Fig. 1. Models of a machine tool based on a reconfigurable triglide mechanisms with vertical (a), inclined (b), and horizontal (c) guides.

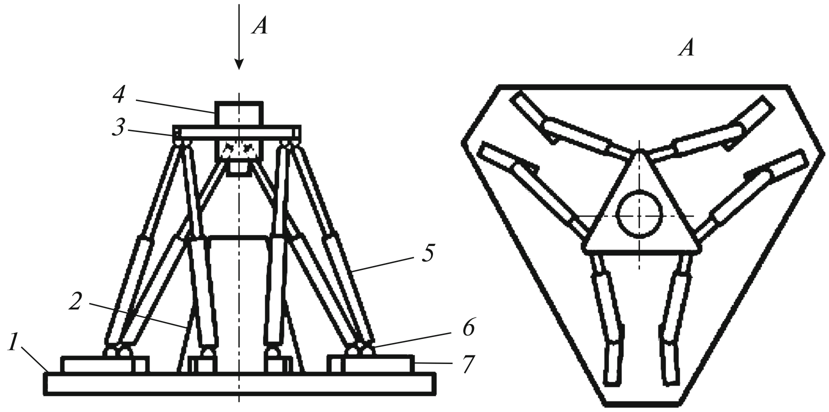

Fig. 2. Hexapod machine tool with adjustable working space: (*1*) immobile platform; (*2*) table; (*3*) mobile platform; (*4*) working element; (*5*) rod; (*6*) hinge; (*7*) guide.

Software for partially automated design of parallel mechanisms was described in [4]. To simplify geometric calculations of parallel mechanisms, division of the set of possible configurations into groups with common geometric features was proposed in [5, 6]. The classification was based on the position of the drive rods on the base and mobile platform.

For each group, a specific set of formulas (calculation templates) has been developed, so as to minimize the number of design calculations required.

In the present work, we classify reconfigurable parallel mechanisms of hexapod type and present formulas for the key parameters of each type.

In Fig. 3, we show a reconfigurable parallel mechanism with six drive rods of variable length.

The drive rods *2* are hinged to mobile platform *1* and to carriages *3*. The carriages may move along guides *4*, which serve as the base of the mechanism. The base radius varies from R_{min} to R_{max}.

The pair of guides *4* and the segments connecting the ends of the guides form a quadrilateral *ABCD*, which may be a rectangle if the guides are parallel or a trapezium otherwise.

The position of the guides on the base may be described by rotational or mirror symmetry or may be asymmetric.

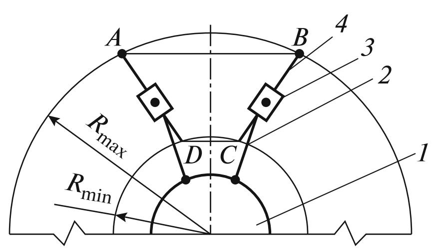

Fig. 3. Guide layout on base: (*1*) mobile platform; (*2*) drive rod; (*3*) carriage; (*4*) guide.

In metalworking machines, the most common configuration is based on rotational symmetry. We may identify four particular cases of parallel mechanisms with rotational symmetry.

1. SYSTEMS WITH A UNIFORM GUIDE CONFIGURATION

In this case, the angle between the guides is the same: $360/n$, where n is the number of guides.

In Fig. 4a, we show a uniform configuration with six guides. In Fig. 4b, we present the key parameters of this system: the orientational angles φ_{1g}–φ_{6g} of the guides on the base. Their values are 0°, 60°, 120°, 180°, 240°, and 300°, respectively.

The length of the guides is

$$L_g = R_{max} - R_{min}.$$

2. SYSTEMS WITH PAIRED PARALLEL GUIDES

In this case, the guides are grouped in pairs on the base. Within each pair, the guides are parallel. The angle between each pair is $360°/2n$, where n is the number of guides ($n = 4$ and 6).

In Fig. 5a, we show six guides in a pairwise parallel configuration on the base, with different positions of the hinges on the mobile platform. In Fig. 5b, we present the key parameters of this system: R_{min}, the minimum base radius; R_{max}, the maximum base radius; L_b, the distance between the hinges on the base; φ_{b1} and φ_{b2}, the positional angles of the hinge on the base with minimum and maximum base radius, respectively; L_g, the guide length; and φ_{1g} and φ_{2g}, the positional angles of the second and third guide pairs on the base.

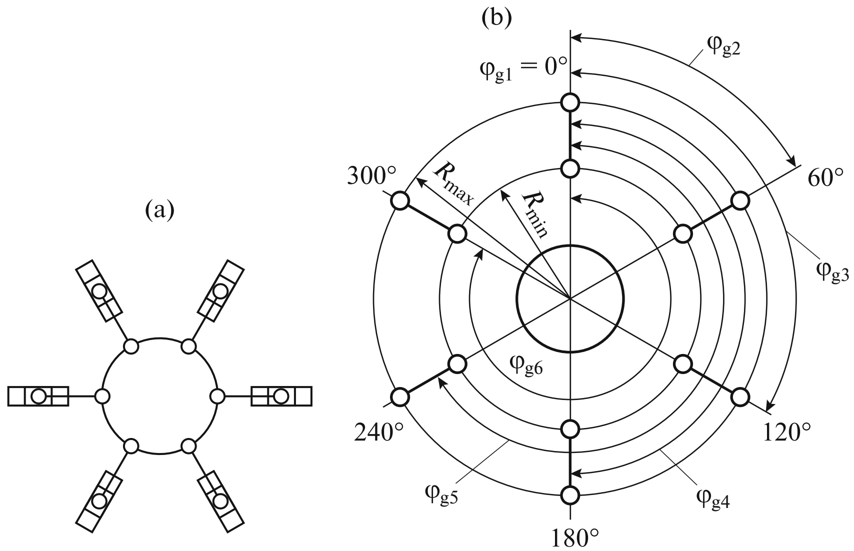

Fig. 4. Mechanism with uniform distribution of six guides (a) and its key parameters (b).

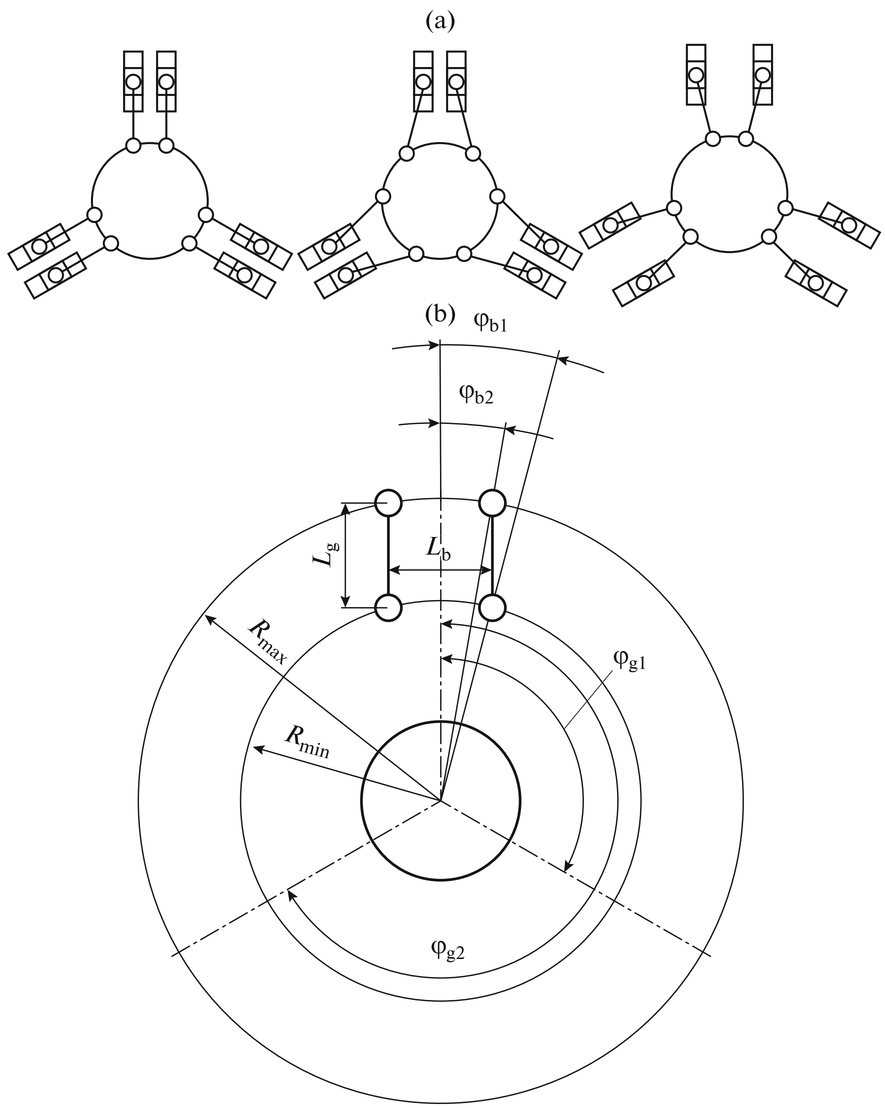

Fig. 5. Mechanism with paired parallel guides (a) and its key parameters (b).

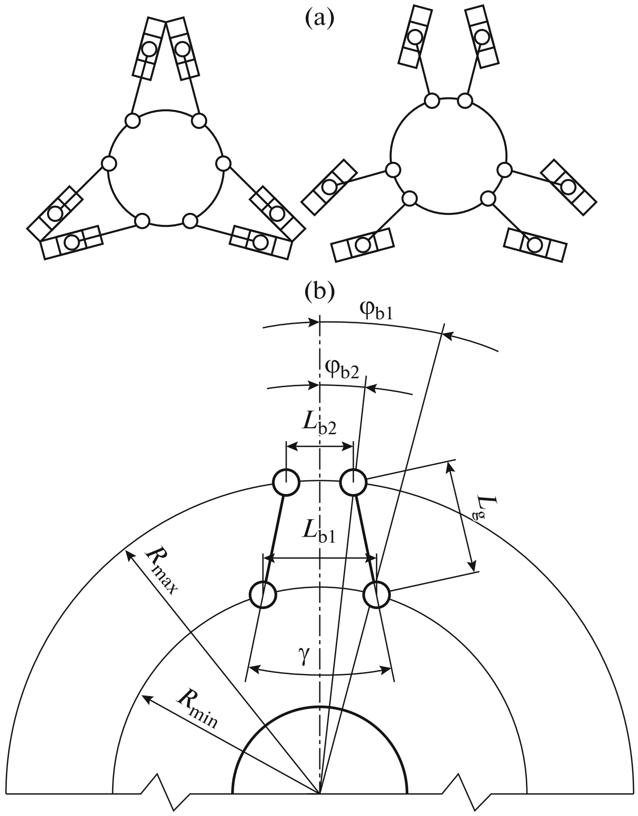

Fig. 6. Mechanism with paired converging guides (a) and its key parameters (b).

The relations between the geometric parameters in this case are as follows

$$L_b = L = \text{const};$$
$$L_b = 2R_{\min}\sin\varphi_{b1} - 2R_{\max}\sin\varphi_{b2};$$
$$L_g = R_{\max}\cos\varphi_{b2} - R_{\min}\cos\varphi_{b1}.$$

3. SYSTEMS WITH PAIRED CONVERGING GUIDES

The guides corresponding to each pair form a trapezium with its base directed toward the center of the figure. In this case, the angle between the pairs is $360°/2n$, where n is the number of guides ($n = 4$ and 6).

In Fig. 6a, we show a set of six guides in converging pairs on the base of a mechanism with different hinge positions on the mobile platform. In Fig. 6b, we present the key parameters of this system.

The relations between the geometric parameters in this case are as follows

$$L_{b1} = 2R_{\min}\sin\varphi_{b1};$$
$$L_{b2} = 2R_{\max}\sin\varphi_{b2};$$
$$L_g = \frac{1}{2}(L_{b1} - L_{b2})\Big/\sin\left(\frac{1}{2}\gamma\right) = \frac{R_{\min}\sin(\varphi_{b1}) - R_{\max}\sin(\varphi_{b2})}{\sin\left(\frac{1}{2}\gamma\right)}.$$

4. SYSTEMS WITH PAIRED DIVERGING GUIDES

The guides corresponding to each pair form a trapezium with its base directed away from the center of the figure. In this case, the angle between the pairs is $360°/2n$, where n is the number of guides ($n = 4$ and 6).

In Fig. 7a, we show a set of six guides in diverging pairs on the base of a mechanism with different hinge positions on the mobile platform. In Fig. 7b, we present the key parameters of this system: L_{b1} and L_{b2}, the distances between the hinges on the base, with minimum and maximum base radius, respectively; and γ, the angle between the guides.

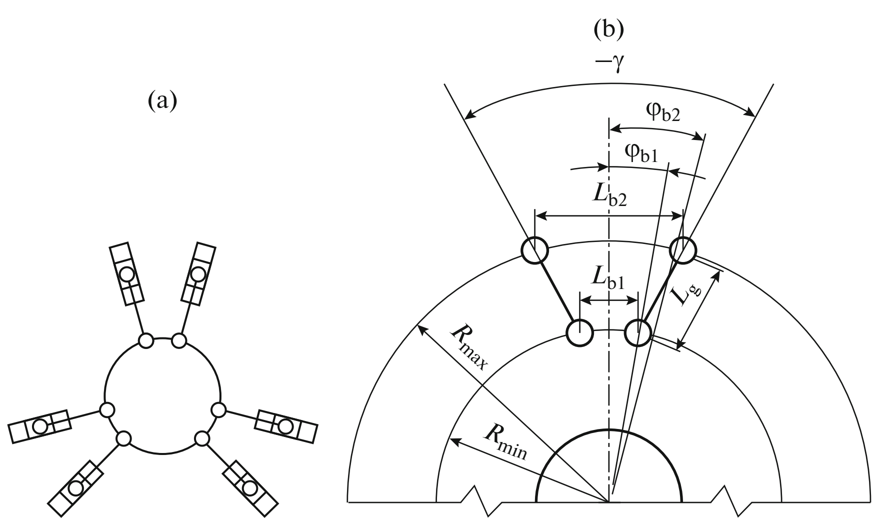

Fig. 7. Mechanism with paired diverging guides (a) and its key parameters (b).

The relations between the geometric parameters in this case are as follows

$$L_{b1} = 2R_{min} \sin \varphi_{b1};$$
$$L_{b2} = 2R_{max} \sin \varphi_{b2};$$
$$L_g = \frac{1}{2}(L_{b2} - L_{b1}) \Big/ \sin\left(\frac{1}{2}(-\gamma)\right) = \frac{R_{max} \sin(\varphi_{b2}) - R_{min} \sin(\varphi_{b1})}{\sin\left(\frac{1}{2}(-\gamma)\right)}.$$

The formulas presented for each case may be used in individual calculation templates for the key parameters, including the initial data; the constraints determining the type of configuration; and the calculation procedure for which the minimum quantity of initial data is needed. For example, in the case of converging guide pairs, the following initial data are sufficient

$$R_{min}, R_{max}, \gamma, \varphi_{b1}, \varphi_{b2}; \text{ or } R_{min}, R_{max}, \gamma, L_{b1}, L_{b2}.$$

CONCLUSIONS

We have classified the theoretically possible reconfigurable parallel mechanisms, in terms of the layout of guides on the base. On that basis, individual calculation templates have been developed for formalized design of reconfigurable parallel mechanisms. Formulas are presented for the key parameters of each type of system.

REFERENCES

1. Pashchenko, V.N., Assemblage of the working area of a six-step manipulator with parallel structure based on a crank mechanism, *Naukovedenie*, 2016, vol. 8, no. 3 (34), p. 135.
2. Kuznetsov, Yu.N., Dmitriev, D.A., and Dinevich, G.E., *Komponovki stankov s mekhanizmami parallel'noi struktury (Machine Constructions with the Parallel Structure Mechanisms)*, Kuznetsov, Yu.N., Ed., Kherson: PP Vishemirsk'kii V.S., 2010.
3. Shchelkunov, E.B., Vinogradov, S.V., Shchelkunova, M.E., and Samar, E.V., Parallel structure mechanisms in metal cutting machines, *Uch. Zap. Komsomol'sk-na Amure Gos. Tekh. Univ., Nauki Prirod. Tekhn.*, 2012, no. 4, pp. 52–61.
4. Shchelkunov, E.B., Vinogradov, S.V., Shchelkunova, M.E., and Posazhennikov, D.G., Automated design of mechanisms with parallel structures and variable length rods, *Tekhnol. Mashinostr.*, 2015, no. 11, pp. 51–55.
5. Shchelkunov, E.B., Vinogradov, S.V., Pronin, A.I., and Shchelkunova, M.E., Application of calculation templates in design of parallel structure mechanisms, *Sborka Mashinostr., Priborostr.*, 2017, no. 9, pp. 427–431.
6. Shchelkunov, E.B., Vinogradov, S.V., Shchelkunova, M.E., and Pronin, A.I., Formalized configurational calculations of parallel mechanisms, *Russ. Eng. Res.*, 2018, vol. 38, no. 8, pp. 581–584.

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