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Mechatronical Module Development on the Basis of Wave Rack Gear for Working Members Drive of Automatized Machines

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Peculiarities of geometry elements synthesis of wave transmission with a rolling (cog) rack, its kinematics and simulation interaction of discrete wedge pushers with rolling rack are considered here. Principles of drive creation and systems of microprocessor control of the mechatronical module of the translation by using wave transmission with the rolling rack as well as the main apprаches in design-technological preparation of its making are presented.

Keywords: translation drive, multi-cam mechanism, wedges-pushers, rolling rack, motion trajectory, cam profile, step (ping) motor.

Introduction

Machine-building progress deals with development of automatized production, particularly machining equipment for different economy fields. Working members translation drives are widely used in multifunction metal cutting and wood-working NC machine tools for plasma and laser sheet material location and spacing of blanks, special roboto-technical systems and other machines. Mechanical firms of a number of countries such as Bosch Rexrot (Germany), Hiwin (Taiwan), SKF (Sweden), Linak (Denmark) have mastered the making of autonomous translation modules. Either ball transmissions of screw-nut rolling motion or rack and pinion gear or toothed belt transmission are used at the working member translation above 2,5–3 m. For drive operation in the automatic control system of given transmissions it is necessary to remove clearances by various design and technological measures which make items more complicated and expensive [1].

Development and research in creating wave rack gears (WRG), that is, a new type of transmission mechanism for drives feed of automatic control machines have been carried out for many years in the Krasnoyarsk Polytechnical Institute of the Siberian Federal University [2, 3]. WRG is a multi-cam mechanism with intermediate links in the form of wedges-pushers interacting with teeth or rollers.

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WRG potentially has good technical-economical specifications and has a set of advantages over other translation transmissions. They are the following ones:

- unbounded transmission quantity and high linear velocity in comparison with ball skew gearing (BSG);
- high reduction in comparison with rack gear (RG);
- contact multi-twoness in rack gearing which contributes to evenness increase of the translation movement comparing with RG;
- constructive mechanism simplicity of clearance choice in rack gearing which excepts the application of doubled kinematic chains;
- satisfactory stiffness values and transmission efficiency which can be related to RG characteristics;
- possibility of WRG creation with partial hermetic sealing of the transmission mechanism which allows to create motion inputs into insulated and even corrosive space.

Problems of WRG development and creation for problems solution of modern machine-building were discussed more than in two tens of publications including the article devoted to the synthesis of the drive link and gearing of wedge pushers with rack rollers [4]. Developed synthesis methods and WRG calculation programs have been protected by seven author certificates and patents on invention, three certificates about program recording for the PC.

Earlier unsolved peculiarities of transmission members geometry, its kinematic synthesis and simulation with WRG wedge pushers interaction with the roller rack as well as formation of 3D transmission models are considered in this article. Information in drive creation and synthesis of microprocessor control by the mechatronical modulus and the main approaches in design technological preparation of its making is given here.

Peculiarities of kinematic synthesis of pusher movement trajectory

Kinematic property of the mechanism is that culminating point of each intermediate links – wedges pushers is to describe flat movement trajectory relative to the rack roller shown in Fig. 1 diagram [2]. Eight sections defined by numbers 0–1, 1–2, 2–3, 3–4, 4–5, 5–6, 6–7, 7–0 are separated out in the shown diagram. Pushers acceleration at distance and approach is carried out on the sections 1–2 and 4–5, and run-out is carried out on the sections 3–4 and 6–7. At this the wedge pusher doesn’t interact with the rack. Rack rollers get translation orthogonally to the pushers movement only at the interaction with them on the linear ascent section 2–3 or 5–6 depending on working motion direction. It is possible to take into account axial clearance in the pushers gearing with the rack by introducing the diagram of upper stand-out in the point 4.

- Input parameters of the trajectory synthesis relative to pusher motion are:
- quantity of wedge pushers Z;
- quantity of pushers interacting simultaneously with the rack rollers χ;
- profile angle of the pusher wedge α_p;
- pitch of rollers set in the rack P_p;
- excess value of the pushers culminating point over coordinate of the contact initial point Δh;
- pushers working stroke h_α, accounted on the initial dependence for wave rack mechanism [1].

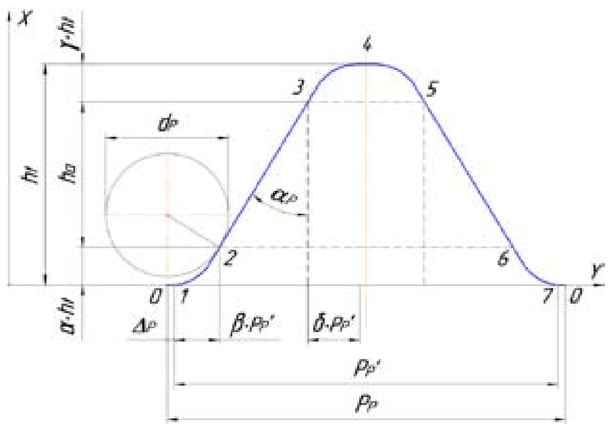

Fig. 1. Motion diagram of the link-pusher relative to the rack roller

$$h_a = \frac{\chi \cdot P_\mathrm{p}}{Z \cdot \mathrm{tg}\alpha_\mathrm{p}} . \tag{1}$$

Output parameters of the trajectory synthesis are:

– calculated pitch P'_p;
– factors β and δ of the camshaft turning angles on the acceleration and run-out section;
– value of complete pusher ascent h_t;
– factors α and γ of the relative pusher motion on the acceleration and run-out sections;
– rack roller diameter d_p.

Algorithm and calculation program in MathCad based on the procedure given in the work [4] have been worked out for output parameters definition. Peculiarities of finished technique of the mechanism synthesis are:

– exclusion of edge interaction of the wedge pusher with rack rollers through introduction of stand-out platforms 0–1 and 7–0 (Fig. 1) with a size

$$\Delta p = \Delta h \cdot \mathrm{tg}\alpha_\mathrm{p} ; \tag{2}$$

– the use of trajectory calculated pitch defined by dependence

$$P'_\mathrm{p} = P_\mathrm{p} - 2\Delta p ; \tag{3}$$

– provision of transition evenness between acceleration sections, linear motion and run-out on the account of factors β and δ equality defined by the dependence

$$\beta = \delta = 0{,}5 \cdot \left(0{,}5 - \frac{1}{P'_\mathrm{p}} \cdot \left(h_a \cdot \mathrm{tg}\alpha_\mathrm{p} + \delta_x \right) \right), \tag{4}$$

where δ_x – is an accounted quantity of the axial clearance;

– the use of calculated value of the rack roller diameter defined by the dependence

$$d_\mathrm{p} = \frac{2\beta \cdot P'_\mathrm{p} - \delta_x}{\cos \alpha_\mathrm{p}} ; \tag{5}$$

– the use of calculation programs of velocity analogues, acceleration and motion of the pusher, taking into account dependence (4) from the work [4].

Profile synthesis in the pusher drive

The scheme of the cam interaction with the roller installed on the pusher with force closure of the kinematic pair which is widely used in the plate cam mechanism has been applied in the WRG under study [5].

Input parameters of the cam profile synthesis are:

– initial cam radius r_0;
– pusher roller radius r_b;
– equations of the pusher relative motion on the sections of its diagram.

Output parameters in the function of the cam turning angle are:

– polar coordinates of the cam profile ρ(φ);
– Cartesian coordinates of the cam profile $X_\rho(\varphi)$, $Y_\rho(\varphi)$;
– pressure angle θ(φ).

The cam profile obtained at the synthesis is close to eccentric in its shape (Fig. 2): its diametrical dimension for the WRG with the rack rollers pitch P_p = 20 mm (ρ_{min} = 11 mm, ρ_{max} = 23,32 mm) at the 180° turning varies in the limits of 0,308 mm.

Small deviation of the cam profile from the cylindrical surface allows to fulfil force closure of the kinematic pair pusher-cam by using a small-sized elastic element with embracing flat springs.

Simulation modeling of pushers gearing with the rack rollers

According to the WRG schematic diagram [2] the cams on the drive shaft are reamed relative to each other in a helical line with the phase angle φ_0 = 360 / Z. At the left or right direction of the helical line the pitch of cam setting along the shaft axis is defined by dependence

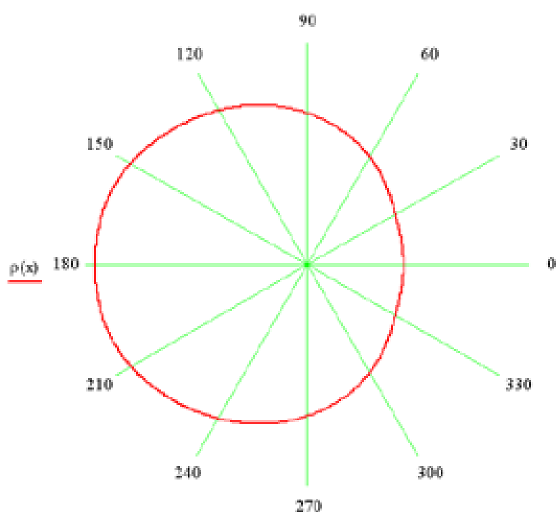

Fig. 2. The WRG cam profile

$$P_t = P_{\text{p}} \cdot \left(1 \pm \frac{1}{Z}\right). \tag{6}$$

Wedge pushers whose rollers interact with cams are arranged in the mechanism through this pitch. Thus, wedge pushers in some angular position of the drive shaft are in different phase position relative to the rack rollers. At this for $\chi = 2$ only two pushers inform motion to the rack, and the rest ones are in contact-free motion with the rack rollers. To select clearances in the rack gearing the mechanism body with pushers is brought nearer to the rack rollers. Here except two driving pushers with the rack rollers two more pushers become valid, which prevent the output link shift. Motion to the output link is transmitted in the wave shape running along the rack axis. Wave-front is the gearing line.

Simulation model of gearing in the transmission has been developed for controlling definition correctness of output parameters of the trajectory synthesis of pusher relative motion and the cam profile as well as required kinematic interaction of driving wedges with driven rack rollers at all angular positions of the drive shaft.

The simulation model was being created by means of CAD (Computer-Aided Design) in the Solid Works environment with a high accuracy of size definition (up to eight signs after comma). Computer-aided design (calculation) in the model was being carried out by linear programming of Microsoft Office Excel application environment, which was integrated into given environment. The simulation model allows to obtain a full review of all pushers interaction with the rack rollers by changing the turning angle of the camshaft at the design stage. If we connect the angular position of the camshaft with the first cam position then all cams will be turned relative to the first one to constant angles multiple to the phase angle value φ_0, and pushers will occupy the certain position relative to the rack rollers (Fig. 3).

The pushers position connected with cams relative to the rack in their reciprocating motion automatically is changed at the camshaft turning to any angle. Interaction in the cylinder-plane scheme is supplied in the points of initial and final pushers contact with rollers.

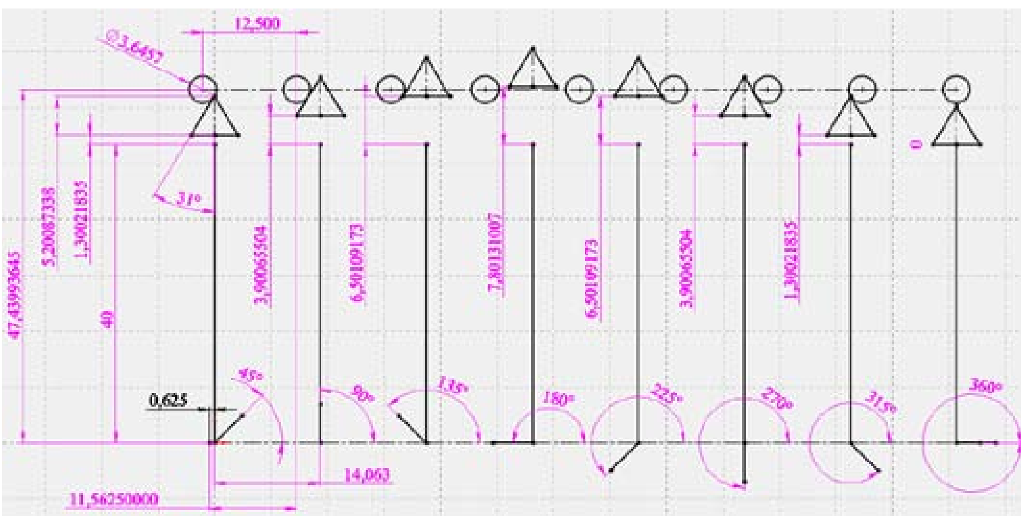

Fig. 3. Simulation model of pushers interaction with rack rollers

The gearing simulation model allows to define the possible links interference or axial clearances value in the kinematic chain.

Structural modulus features

The translation modulus (TM) presents a mechatronical device consisting of the converter of the drive shaft rotary motion into the reciprocating motion of wedge pushers; the roller rack, the stepping motor connected with the drive shaft through backlash-free coupling; and an electric motor and control systems. The TM rack in feed drives of machine working members can be installed either on fixed or movable link. The main TM construction [3] is shown in Fig. 4.

The module converter consists of the body 1, the camshaft on bearing supports 2, pushers 3, pusher guides 4, the translation rolling-contact bearing 5, rail guides supports 6, a load-carrying structure 7, a backlash-free coupling 8, an intermedial sleeve 9 and an electric motor 10. The rack 11 with rotatable rollers is installed on the load-carrying structure 7. On turning the electric motor rotor 10 the camshaft 2 displaces pushers 3 into the guides 4, and pushers wedges interacting with rollers 12 of the rack 11 displace the module body 1 together with all construction elements along the rail guides 6. Different types of working members can be connected with the body 1 which need to be informed dimensional translation. Electric power supply is accomplished by the cable (it is not shown in Fig. 4).

The module components are characterized by simplicity and adaptability to manufacture (workability) but require highly precise equipment that is specific to the feed drives. A variety of translation modules with the rollers pitch in the rack P_p = 12,5; 16; 20; 25; 30 mm can be produced according to the construction given in Fig. 4. At this the module technical characteristics will gain values presented in Table 1.

At present 3D-models of components and assemblies of the TM construction with rack rollers pitch P_p = 12,5 mm and 20 mm have been developed. The converter mass of the TM with the pitch of 12,5 mm (without motor) is 4,5 kg and has overall dimensions 195x87x77 mm.

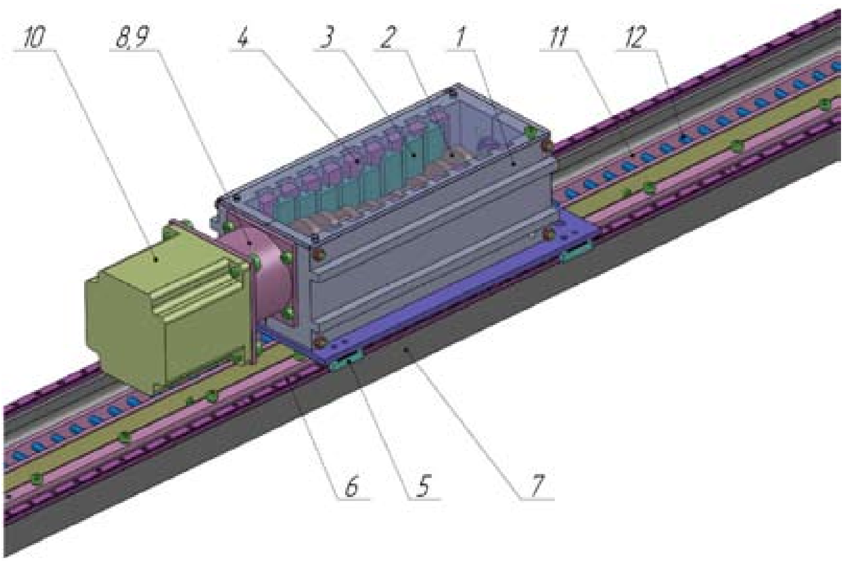

Fig. 4. The translation modulus

Table 1. Technical characteristics of the translation modules

Parameter	Symbols	Dimensions of a quantity	Rack rollers pitch P_p, mm				
			12,5	16	20	25	30
Rack roller diameter	D_d	mm	3,6	4,6	5,75	7,2	8,7
Tractive force	F_t	N	500	900	1400	2200	3200
Translation velocity	V_p at synchronous engine rotational speed 1000 rpm	m/min	12,5	16,0	20,0	25,0	30,0
Calculated efficiency	η	%	85	87	87	90	90
Calculated power of drive motor	W	W	100	180	355	675	1200
Calculated maximum torque	T	Nm	1,45	2,6	5,1	9,7	17,3

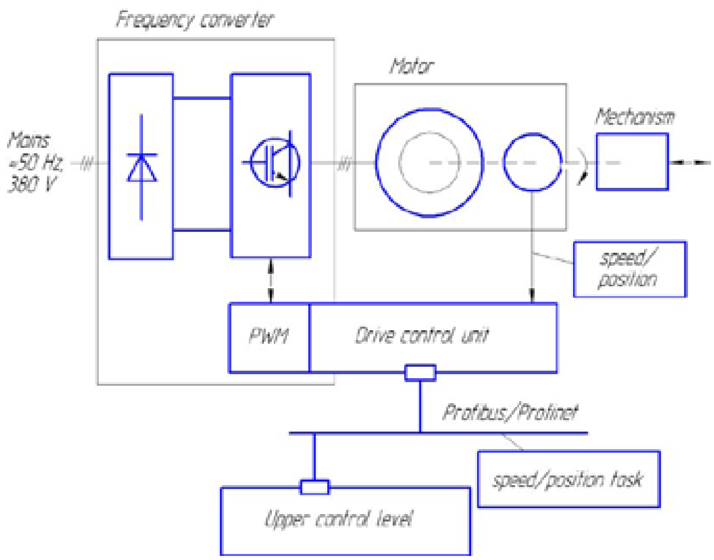

Fig. 5. Functional scheme (diagram) of the TM drive

The drive and module control system

Either step motor (Fig. 4) or alternating current motor with frequency converter on the inverter basis with pulse-duration modulation (PDM) and microprocessor control system (Fig. 5) can be applied in the TM drive [6].

The drive power can be chosen in the high range of mechanism requirements. Absence of brush-collector mechanism in the motor makes the drive simple in construction, reliable and durable.

Microprocessor control system provides control-quality indexes which differ a modern servo drive: a high range of speed and moment control, high speed of response and precision of task fulfilment, a high level of emergency protection; flexibility in drive configuring at adjustment to the peculiarities of the mechatron module application; presence of the communication channel with upper control level allows to integrate the mechatron module into the system of integrated automation and provide remote mains-operated access to the module.

Absolute linear displacement transducer is added to the system for more precise positioning if necessary.

Work preparation of the TM making

The principle of highly precise translation drives creation realizable by the TM construction defines a series of requirements and problems of its making work production:

- definition of specifications optimum values provided at the module assembly and its components machining on the basis of adopted parameters of its official purpose;
- provision of high contact accuracy between interacted surfaces of the module components depended on the requirement to the accuracy of displacement it created (accumulated error is not more than 30 mkm on the 500 mm length);
- requirements formation and implementation to workability of the module components constructive shapes defined by a distinctive feature of their official purpose;
- absence of compensative links in the wave transmission construction causes accuracy problem solution at the module making on the basis of interchangeability procedures and as a result provision of high requirements to the linear dimensions accuracy, geometric shape and relative position of interacted surfaces and the main design bases of the module components;
- application of technological methods of finishing out, providing high requirement fulfilment to macrogeometry and roughness of performed surfaces;
- application of special schemes and control methods of precision parameters of the module components and displacements created by this module;
- application of modern high production machine-tool equipment and development of management programs for the TM components making;
- design work and machining attachments manufacture for performance of machining operations;
- specifications correctness to the manufacture and requirements to workability on the basis of tests of module prototype specimen.

The module prototype specimen is being brought to a commercial level, route-operating production processes are being developed, operations in TM parts making are being designed. Alternatives of technological provision of the module precision and stiffness, as well as used machine-tool equipment and workability are considered. Experimental try-out of the specimen structure and its application in produced wood-working machines with automated management is supposed by the investigation plan.

Conclusions

As the result of carried out investigations:

- algorithms and output parameters of the trajectory synthesis of the pusher relative motion and profile coordinates of the module driving cams have been developed;
- simulation model of pushers wedge gearing with the rack rollers (cogs) has been created;
- 3D-models of elements and the module construction assemblies have been worked out;
- the principal approach to the creation of the management system and the module drive as well as its production practice has been developed.

The TM development on the basis of new transmission, that is, wave one with a cog rack will be a step in making importreplacing products of domestic machine building.

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Разработка мехатронного модуля на основе волновой реечной передачи для привода рабочих органов автоматизированных машин

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Рассмотрены особенности синтеза геометрии элементов волновой передачи с роликовой (цевочной) рейкой, ее кинематики и моделирование взаимодействия дискретных клиновых толкателей с роликовой рейкой. Изложены принципы создания привода и системы микропроцессорного управления мехатронного модуля поступательного перемещения с использованием волновой передачи с роликовой рейкой, а также основные подходы в конструкторско-технологической подготовке его производства.

Ключевые слова: привод поступательного перемещения, многокулачковый механизм, клинья-толкатели, роликовая рейка, траектория движения, профиль кулачка, шаговый электродвигатель.