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Optimization of technological process for assembly on rotary assembly machines

Promotion work abstract

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GENERAL CHARACTERISTIC OF WORK

Actuality of theme

Automation of technological process for assembly is of interest for researches for the several reasons. At first, on modern manufacture labour input of assembly works is great enough and depending on object of assembly and conditions of manufacture varies within the limits of 20-80% from the labour input of products manufacturing. And, second, in comparison with other technological processes, assembly operations are automated least - the level of automation does not exceed 6 % - 7 % (on the data for 2000).

From all stages making typical technological process for assembly, the most labor consuming are the stages connected with mutual orientation and interface of assembled details. Therefore significant reserves on reduction of labor input of assembly operations lay in this area.

Use of one-item and multi-item assembly machines allows realizing the automated assembly of rather complex products. However the greatest technical and economic effect at complex automation of assembly processes turns out from application automatic rotary assembly machines and automatic transfer lines, in which products from operation on operation (from a rotor on a rotor) are transferred in preliminary focused position.

Researches of some authors are devoted to questions of automation of assembly of mechanical engineering and instrumentation products. Among them there are following authors: B.S.Balakshin, P.I.Bulovskij, A.N.Gavrilov, V.S.Korsakov, A.N.Malov, M.P.Novikov, A.N.Rabinovich, K.J.Mutsenek and etc.

The analysis of references has shown, that questions of reliable work of the assembly equipment and maintenance of accuracy of relative orientation of assembled details are developed insufficiently. For this reason the created automatic devices not always provide reliability of realization of assembly process, that in turn there is a basic brake in development of assembly manufacture.

It does not allow to count available decisions optimum and forms the basis for search of new decisions, which would provide fuller use of functionalities of rotary devices at performance of assembly operations by them.

The purpose of work

The purpose of the present work is studying and optimization of technological processes for automatic assembly on high-efficiency rotary the equipment.

For achievement of an object in view it was necessary to solve the following problems:

- to investigate the methods of vibrating assembly using a various sorts of a trajectory;
- to establish the optimal trajectory of moving of assembled details axes while auto search process - as the basic criterion of optimization to use minimal time of details connection;
- to consider use of vibrations on high-efficiency rotary equipment, which, for example, is used in Daugavpils on "Driving Chain Factory Ditton ", in Riga on SIA "Spilva", at the Tula Driving Chain Factory, etc;
- to define influence of speed of details relative movement, forms of a trajectory, amplitude and frequency of fluctuations and other factors on the details assembling and consider the optimum variants of modes of rotors and details movement;
- to define the optimum form of edges of the connected surfaces of details - criterion of optimization to use force of friction on contacting surfaces;
- to define influence of the form and the sizes of edges on the allowable deviation of machine part's axes while using vibration methods;
- to reveal influence of detail misalignment in the positioning device on machine parts joining process;
- to examine the influence of forces on the machine parts in the vibro-assembling process;
- to examine the detail movement path in the active zone.

Methods of researches

To the decision of the primary goal - optimization of technological process for assembly on rotary assembly machines it was applied two kinds of optimization: structural and parametrical optimization. At various design stages of technological process of assembly and a choice of the optimum decision various criteria of optimization were defined and some methods were used, namely: methods of analytical research, empirical

methods and modeling. At the decision of the equation of movement of a detail on an active site of assembly the method of "sewing together" was used. For computing experiments used personal computer IBM PC, programs "AutoCAD 2000", "Mathcad 8".

Scientific innovation

The following results of dissertational research are new:

- the method of automatic assembly on rotary automatic devices, providing reliable interface of details to a significant error of their relative orientation before connection is investigated;
- conditions at which there is a guaranteed connection of details at application of vibrations are determined;
- influence of the forces working on collected details, on conditions of interface is determined at vibrating assembly;
- optimum modes of movement of assembly rotors and collected details are determined.

Practical value

As a result of optimization of technological process of assembly on rotary automatic devices the method of connection of details is determined; an optimum trajectory of movement is determined too; the optimum modes of the movement providing absolute connection of details, which has acted on assembly, are determined; the optimum form of edges of connected details is determined. For engineering calculations is proposed a calculating method of the vibrations mode of auto search devices and are given nomograms for such auto search devices. All listed above enables to provide a required level of economic efficiency of assembly process on rotary assembly machines used, for example, in Daugavpils on "Driving Chain Factory Ditton ", in Riga on SIA "Spilva", at the Tula Driving Chain Factory, etc.

On defense the following positions are taken out:

1. Research of methods of the vibrating assembly using a various sorts of a trajectory;
2. An establishment of the optimal trajectory of moving of connected details axes at auto search (the basic criterion of optimization is minimal time of details

connection);

3. Research of application of vibrations on high-efficiency rotary equipment;
4. Definition of influence of speed of relative movement of details, forms of a trajectory, amplitude and frequency of fluctuations and other factors on a details connecting and consideration of optimum variants of modes of rotors and details movement;
5. Definition of the optimum form of edges of connected surfaces of details at assembly (criterion of optimization - force of friction on contacting surfaces);
6. Definition of influence of the form and the sizes of edges on size of a maximum deviation at vibrating assembly;
7. Revealing influence of detail misalignment in the positioning device on machine parts joining process;
8. Research of influence of forces on the details in the vibro-assembling process on details joining process;
9. Research the detail movement paths in the active zone.

Approbation of work

The basic scientific positions and results of promotion work have been reported and have received a positive estimation at the following conferences and seminars;

- Student conference "38. RTU studentu Zinātniski - tehniskā konference" (Rīga, Latvia, April 21-25, 1997);
- MET-97. International Conference "Welding. Technologies, Equipment, Materials". - Rīga, Latvia, 1997;
- Student conference "40. RTU studentu Zinatniski - tehniska konference" (Rīga, Latvia, 1999);
- International scientific and technical conference Сварка, высокочастотная техника, электротермия, металлообработка" "(S.Peterburg, Russia, 1999);
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- 44.International Scientific Colloquium. Technical University of Ilmenau. - Ilmenau, Germany, 1999;
- III International Conference "Welding. Technologies, Equipment, Materials, Related Technologies". - Rīga, 1999;
- Student conference "42. RTU studentu Zinātniski - tehniskā konference"

(Rīga,Latvia, 2001);

- II International Conference for Young Scientists on Bionics, Biomechanics and Mechanics. - Varna, Bulgaria, 2001;
- Student conference "43. RTU studentu Zinātniski - tehniskā konference" (Rīga, Latvia, October 10-14, 2002).
- 47. InternationaI Wissenschaftliches Kolloquium. Technische Universitat Ilmenau. - Ilmenau, Germany, 2002;
- Student conference "44. RTU Starptautiskā Zinātniskā konference" (Rīga, October 9-10, 2003).

Publications

By results of the executed researches and development 10 scientific and technical clauses are published.

Structure and volume of work

The promotion work will consist of the introduction, four chapters, the conclusion and conclusions on work, the list of the literature in amount of 137 names. Total amount of promotion work - 168 pages, including basic computer text with 73 figures and the list literature on 10 pages.

THE BASIC CONTENTS OF WORK

In introduction the actuality of theme and necessity of carrying out of the given work are proved, are formulated the purpose and problems, and also basic provisions of the dissertation are stated.

In the **first chapter** is made the review of the literature devoted to the researched question; are considered: rotary machines and automatic transfer lines for operations of assembly; reliability and measures on increase of reliability of assembly technological process realization on rotary devices; trajectories of relative movement of connected details axes by automatic search, and also the research problem is put.

Automatic rotary devices apply in various industries, but significant economic benefit at complex automation gives application automatic rotary machines (RM) and lines (ARL) in assembly manufacture that speaks a number of their positive properties and advantages in comparison with other kinds of automatic systems.

Professors L.N.Koshkin, I.A.Klusov, V.F.Prejs underline, that systems of rotary machines allow to receive a high degree of productivity (theoretically boundless). It is reached by overlapping assembly with continuous transportation; an opportunity of automatic change of the tool which has lost working capacity without a stop of the machine; preservation of operating ratio of the several machines included in a line due to automatic change of toll blocks (TB), automatic additional charging of a thinning stream of details and interlinear stocks of details.

Questions of reliability of realization of technological assembly process and maintenance of accuracy of relative orientation of connected details since the opportunity and expediency of automation of assembly process depends on their decision as such are the basic part of the theory of automation of assembly process. To the decision of these questions are devoted B.S.Balakshin, PXBulovskij, A.N.Gavrilov, V.S.Korsakov, A.N.Malov, M.P.Novikov, A.N.Rabinovich, KJ.Mutsenek research and others authors.

The reasons of details disconnection (not performance of assembly process) are connected, on the one hand, in the assembly equipment, and to another - in the details acting on assembly and a choice of technological assembly process. In some cases refusal can occur as a result of simultaneous action of the named reasons. Thus development and definition of optimum technological process of automatic assembly on rotary automatic devices and automatic transfer lines will consist of six basic stages: the analysis of reliability of work of the assembly equipment; the analysis of product adaptability to manufacture, which assembly is supposed to be made automatically; definition of assembly

restriction; a choice of a method of assembled product accuracy achievement at automatic assembly; a choice of the location mode and calculation of assembled details' relative position accuracy.

At automatic assembly the automatic device will assemble the details only in the event that the assembly automatic device together with connected details forms such dimensional circuit in which the distance between axes of details Δ_{Σ} does not exceed a permissible deviation δ. However, even if details are made at the rate of full interchangeability, additional errors of parts of the dimensional circuit belonging to the assembly automatic device, frequently lead to that the part of details will not be collected.

On the part of the assembly equipment except for the imperfect kinematical scheme to refusals can result such circumstances, as an imperfect design of separate units of the automatic device; poor-quality manufacturing of the details acting on assembly; wrong position of collected elements at their receipt in reception jacks TB, etc.

Problems of reliability of work of the automatic assembly equipment were considered by I.L.Blaer, V.V.Kosilov, V.I.Smiljansky, B.A.Lobzov, K.J.Mutsenek, R.A.Mikelson. According to their researches, reliability of work of assembly automatic devices can be raised by application of the various measures leading to elimination of the reasons, causing refusals, or to reduction of their influence. The correct choice of the kinematical scheme and design of units of the assembly equipment, centralization of its designing and manufacturing on the basis of the normalized units, a choice of rational control-managing system of the assembly automatic device checking correctness of performance of separate operations and in appropriate way reacting on revealed defects concern to such measures.

The analysis of the various factors influencing reliability of assembly process, carried out on the automatic equipment, enables to establish the basic ways of increase of reliability, namely due to creation of rational designs of products, technological for automation of assembly and selection of optimum technological process of assembly.

Collected products design adaptability to manufacture for automatic assembly has very big value, because in many cases it defines not only efficiency of assembly process automation, but also expediency or automation opportunity in general. Improvement of design adaptability to manufacture labor input of assembly can be lowered up to 20% and the cost price of product manufacturing on 5 - 10%.

The concept of design adaptability to manufacture for automatic assembly covers both a design of all unit or product, and the design features of separate details determining their suitability for automatic orientation, submission and mounting on a base detail.

Opportunities of improvement of design adaptability to manufacture at assembly are rather in detail considered by P.I.Bulovsky, B.M.Soshnikov, A.N.Gavrilov, I.M.Pavlov, V.V.Ivanov, V.I.Smiljansky, etc., who analyzed significant number of designs of devices units in which connections are fixed with the help of various technological methods. In the mentioned works, and also in the general rules it is shown, that the estimation and maintenance of product adaptability to manufacture a need to be made in view of influence of assembly stages on a collected product as a whole, its units, details and materials.

Preparation for product assembly automation demands design adaptability to manufacture analysis realization for what details adaptability to manufacture precise attributes determination and assembled product as a whole is necessary. Such estimation allows to solve the problem on opportunity of product existing design automation assembly process and also to plan design modernization ways, allowing automating assembly process.

Now a number of quantitative estimation techniques of products design' adaptability to manufacture for conditions of automatic assembly offered by M.V.Vejnberg, M.S.Lebedovsky, V.A. Jahimovich, A.K.Karklinsh, etc. is known. In a technique developed by K.J.Mutsenek, specificity of work rotary equipment is taken into account, recommended private estimations to separate attributes of details adaptability to manufacture and assembly units as a whole are resulted. Parameters of adaptability to manufacture are defined as average arithmetic private estimations in view of weight factors of separate attributes.

At selection of optimum technological process of assembly two primary goals are solved: the first - definition of optimum location modes of collected details, executive mechanisms, bunker, submitting and other devices, and the second - definition of quality standard of performance by the chosen assembly equipment of collecting conditions. Both problems are solved proceeding from definition of assembly restriction.

V.V.Kosilov, K.J.Mutsenek, M.S.Lebedovsky, I.A.Usenko, V.K.Zamjatin researches are devoted to definition of conditions of automatic assembly of details with cylindrical form.

Assembly restrictions at automatic assembly is carried out in the event that on an assembly position the total error of assembled details' relative orientation Δ_{Σ} does not exceed on size of allowable value of assembled details axes' relative displacement δ, i.e.

$$\Delta_{\Sigma} \leq \delta. \qquad (1)$$

The revealed assembly restrictions appreciably predetermine calculation and a selection of the optimal location modes and of a method of connection accuracy achievement.

In some cases the found assembly conditions of any details are very rigid in the precision attitude and location mode selection is sometimes inconvenient to the automatic assembly problem decision, as they cannot provide high requirements of assembled details relative position accuracy satisfying assembly restrictions. Here repeatedly it is necessary to reconsider specifications on assembly object and details making it, including revision of the sizes and admissions on the details, which are included in object of assembly. These measures are necessary to receive such assembly restrictions, which allow selecting appropriate location mode for maintenance the necessary accuracy of assembled details relative position, deciding an automatic assembly problem.

At details automatic assembly on rotary automatic devices all methods of connection accuracy achievement can be applied except for a method of fitting in place. Calculation and a selection of location modes depend on the accepted method of connection accuracy achievement, and as following from this, quality of assembly, complexity, serviceability of the automatic assembly equipment and economic parameters of the developed system. From these positions the method of full interchangeability provides the best results. It enables to provide assembly quality, not complicating the assembly equipment to provide reliability of the equipment work and high efficiency.

So, on the basis of the chosen method of connection accuracy achievement and the found assembly restrictions the optimal location modes that provide errors of relative position collected details, not exceeding allowable errors on assembling conditions are defined.

Depending on a combination of these location ways by S.S.Bizjaev it was deduced 25 location ways of cylindrical form details. Research of ways of location allows to reveal interrelation between accuracy of assembled details manufacturing, accuracy of location and interface restriction. Under S.S.Bizjaev's statement, applying various ways of location it is possible to change assembled details interface restriction with the same tolerances and the same basing devices accuracy in some times.

Depending on the selected assembled details location mode select bunker, orientation, transport, control and other assembly automatic machines devices.

For the decision of a question on a basic possibility or impossibility of assembly operation performance proceeding from the assembled product sizes and the accepted details location mode on the automatic assembly equipment position carry out calculation of assembled details relative position accuracy (by calculated or experimental method) and

compare the received details interfaced surfaces deviation to allowable size. If necessary plan measures, which increase accuracy of the automatic assembly equipment's details and elements.

Researches in the field of a details assembling on the automated positions of automatic devices and automatic transfer lines are based on M.V.Medvid, A.N.Rabinovich, A.N.Malova, V.S.Korsakov, N.A.Borodachev, P.F.Dunaev works and of some other authors. Some calculation procedures of automatic assembly process accuracy were offered.

Calculation procedures of automatic assembly process accuracy includes several stages and consists in definition of a total error of assembled details axes relative positioning before their connection and its comparisons to admitted size.

B.A.Lobzov gives the analysis of mistakes, which influence to accuracy of relative orientation of details with use of the general methods of calculation of dimensional circuits. In KJ.Mutsenek and B.A.Lobzov works the design procedure of accuracy of automatic assembly process is offered and some methods of maintenance of a details assembling are proved.

On the basis of a guaranteed backlash in connection, A.A.Gusev, with the help of calculation on a maximum and a minimum, has defined size of the greatest maximum deviation of details, which are interfaced on cylindrical surfaces.

Doctors of Engineering science professor A.N.Malov and professor A.B.Paknis investigate a assembling of details at distribution of a total error of their relative orientation to positions of assembly and a radial backlash under Simpson's law.

A.G.Gerasimovym considered questions of accuracy of assembled details interface.

So, realization precision researches of assembly process allows to estimate reliability of assembly process performance and, hence, to handle the problem on an opportunity and expediency of assembly process automation, and also to plan actions which would allow to raise process accuracy and its reliability.

A number of authors (A.N.Rabinovich, A.N.Malov, V.M.Savishchenko, B.A.Lobzov) specify necessity of performance of facets on interfaced surfaces for reduction of size of assembly force. Researchers A.M.Girel, N.M.Karelin, V.G.Bespalov, KJ.Mutsenek, B.A.Lobzov, A.N.Rabinovich who analysed assembly of details with facets came to a conclusion that it is necessary to reduce rigidity of technological system. However questions of a choice of the rational form of facets, questions of the account of facets with radiuses (roundings off) on interfaced surfaces and their influences on size of a maximum deviation are developed insufficiently.

It is shown, that from all methods raising reliability of realization of automatic assembly process in the block of an assembly rotor, the most effective is use of a principle of vibrating system of casual search in which mutual search of details axes in a plane is provided, perpendicular to a direction of assembly. The search engine entered into technological system moves one or both details before hit of a detail axis to a zone of a maximum deviation, and assembly appears possible even at significant size of an initial error of relative orientation.

As such search engines can serve a various sort of the device such as mechanical, pneumatical, electromagnetic and other devices that provide compulsory details moving on the certain trajectory.

Examples of the various trajectories providing mutual search of interfaced details axes, and mechanisms for their realization, offered by A.N.Rabinovich, B.A.Lobzov, K.J.Mutsenek, N.M.Karelin, A.M.Girel, V.G.Bespalov, V.M.Savishchenko, F.A.Sudniek and other authors are resulted. However there is no precise picture what of trajectories of relative moving details is the most rational for automatic assembly on rotary automatic devices.

It is found out, that theoretical bases of vibrating methods of assembly, especially the questions connected to calculation of optimum modes of fluctuations (speed of relative movement in a direction of transport and vibrating moving, amplitudes of fluctuations, frequencies, etc.), in view of the form of edges of interfaced surfaces, the forces working on a detail during the contact moment, and the form of a trajectory of relative movement are completely insufficiently developed.

Promotion work is devoted to definition of optimum technological process of automatic assembly on rotary automatic devices for a way with application of the vibrations, providing interface of details to a significant error of relative orientation before connection.

Research is executed for a case of details connection (type platen-cartridge) as the systems of rotary machines are the capital equipment for connection of details with cylindrical surfaces.

In the second chapter of the promotion work is established, that the optimal trajectory of moving of assembled details axes at auto search is the trajectory sine wave or close to a sine wave curve. Criteria of optimization, for definition of an optimum kind of a trajectory, have been chosen: minimal time of a detail axis presence in a backlash field, useful length of a way of detail search and efficiency of trajectories.

The way of assembly at a sine wave trajectory of the movement is investigated, allowing to raise reliability of process of details automatic connection without toughening requirements to accuracy of their manufacturing and accuracy of units of the automatic assembly equipment. The given method is realized because assembled details move on a position of assembly with different linear speeds, and one from details is informs the oscillatory movement in a cross-section direction. Due to it automatic search of details interfaced surfaces is provided within the limits of a zone of their possible deviations.

For reception of different speeds of assembled details transport movement the axis of assembly adaptations are displaced relatively to rotors dividing circles (Fig. 1) on size ε. Settlement dependences are received and constructed nomograms for definition of size ε.

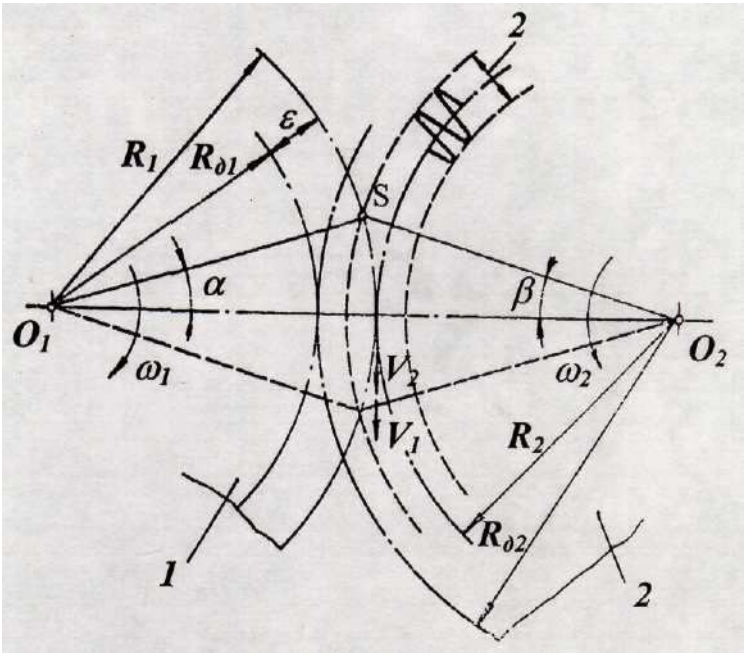

Fig.l. The scheme of assembly at displacement of assembly adaptations axes relatively to rotors dividing circles on size ε.

In promotion work it is shown, that conditions of assembly will be optimum if during passage by a detail of trajectory working site the difference of details ways exceeds size of details possible deviations from their settlement position. This requirement is carried out provided that

$$R_1\alpha - R_2\beta = \Delta_{\Sigma y}, \qquad (2)$$

where R_1 *un* R_2 - distances from assembly adaptations axes up to the centers of rotors rotation;

α *un* β - corners of a working site of details trajectories;

$\Delta_{\Sigma y}$ - an error of relative orientation of details in a tangential direction.

Thus the maximal angular speed of the rotor established in the assembly automatic transfer line with an external contact of dividing circles, is limited to size

$$\omega_1 = \frac{4\alpha\nu\delta}{\Delta_{\Sigma y}} \qquad (3)$$

where ν - frequency of vibrator fluctuations;

δ - maximum deviation of assembled details axes.

Frequency of rotors rotation can be increased at increase in frequency of fluctuations or a corner of a working site *a* which, in turn, increases at additional displacement of one detail in a radial direction for size A -$\Delta_{\Sigma x}$ (Fig- 2), where $\Delta_{\Sigma x}$ - an error of relative orientation of details in a radial direction.

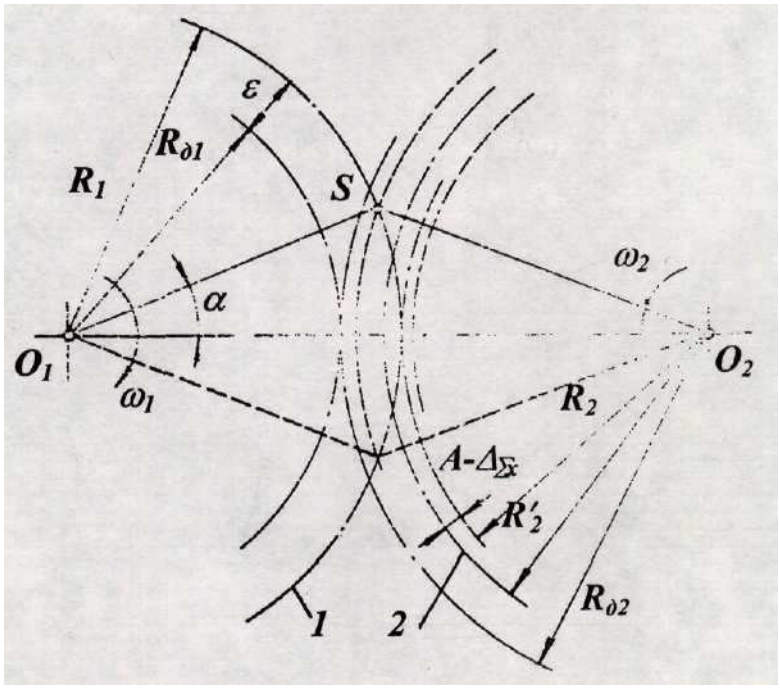

Fig.2. The scheme of details assembly on rotors at additional displacement of detail *2* on size A-$\Delta_{\Sigma x}$.

The size of optimum displacement on rotors makes

$$\varepsilon_{\text{опт}} = R_{\partial 1}\left(\frac{1}{\frac{2b\sqrt{i_{21}}}{\Delta_{\Sigma y}} - 1}\right), \qquad (4)$$

where i_{21} - the transfer attitude of a rotor drive;

$R_{d\partial i}$ - radius of dividing circle of a conducting rotor;

b - settlement size of ellipse semiaxis of a point trace at change of displacement €.

The length of a working site of a trajectory can be increased considerably at assembly of details on rotors with an internal contact of dividing circles or on rotary-chain devices.

Thus the trajectory of movement of a fluctuating detail on a site of assembly with a sufficient degree of accuracy can be approximated by a sinusoid. Application of other kind trajectories probably, but is connected to complication of devices for their realization. The trajectories received due to fluctuations, directed under some distinct from direct corner to transport movement, lead to reduction of a zone of overlapping of relative movement trajectories and worsen conditions of details assembly.

In promotion work it is shown, that speed of relative transport movement v_y depends on size of a maximum deviation δ, designed, proceeding from the geometrical sizes of interfaced surfaces, from frequency of fluctuations v the vibrator and from a parity of amplitude sizes of fluctuations A and errors of relative orientation of details $\Delta_{\Sigma x}$, and changes in limits

$$4\,\delta v > v_y > 2\,\delta v \ . \qquad (5)$$

Speed of details vibrating moving v_x at small amplitude of fluctuation $A_x \cong \Delta_{\Sigma x}$ should be defined as the average speed, passed of the normal law of meeting moment speeds distribution.

In the **third chapter** of the promotion work it is shown, that on assembled details in a point of their contact the following forces operate: assembly force P ; force of a detail clip Q to directing surfaces of assembly adaptations; the force F created by the vibrator and friction forces between contacting surfaces of details and between details and directing surfaces of an assembly head and the assembly adaptation.

It is found out, that from standard parameters of a roughness only two Ra, Sm influence on assembly process.

It is determined the optimum form of edges of interfaced surfaces. Force of friction between contacting surfaces is chosen as the criterion of optimization. It is found out, that the optimal are edges with radiuses. It is found out, that the optimal are the edges with rounded form.

It is shown, that at vibrating assembly the maximum deviation is defined by size of details relative moving in a plane of vibrations at which there is a probability of their connection, and depends on a relative positioning of a trajectory of relative movement and a zone of a maximum deviation.

Depending on the chosen mode of fluctuations the trajectory of an axis of fluctuating detail can cross a zone of a maximum deviation one or some times on lines, which are taking place from the center of deviations zone on some any distance.

For maintenance of crossing with a sine wave trajectory with the minimal amplitude of fluctuations the zone of a maximum deviation at a presence of its center in any point inside an ellipse of errors dispersion Δ_{Σ} it is necessary, that the step of a trajectory had the maximal size equal 2δ.

Depending on a parity of the forces working on assembled details in a point of their contact (assembly force, force of a clip and the vibrator and force of friction between contacting surfaces), at a contact edges with rounded form three various characteristic cases are observed:

1. The detail will stop oscillatory movement and assembly will be carried out, if a difference of corners will be

$$a - \varphi > \rho, \tag{6}$$

where α - corner of an inclination of a tangent to a horizontal in a point of details contact;

φ- corner between equally effective and a direction of assembly;

ρ - corner of friction.

2. The detail will stop oscillatory movement and will nestle with rounded edge to an edge of assembled details. Assembly will take place during the second semiperiod of fluctuations, i.e. at movement of a fluctuating detail in the opposite direction at performance of conditions

$$|\varphi - \alpha| < \rho, \tag{7}$$

$$\alpha + \beta > \rho, \tag{8}$$

where β - corner between equally effective from assembly force and force of the vibrator and a direction of assembly.

3. The contact of edges with rounded form will not change character of fluctuations and assembly will be failed, if

$$\varphi - \alpha > \rho. \tag{9}$$

From these three cases of assembly the greatest interest represents the second case - the automatic assembly with the maximal size of a maximum deviation $\delta_в$ at use of vibrations.

The analysis of process of details contact with rounded edges shows, that the automatic assembly with application of vibrations is provided even then when edges of details at initial contact come against each other a little (Fig. 3). The allowable size of such overlapping with can be found from expression

$$c = (r_1 + r_2)(1 - \sin\alpha), \tag{10}$$

where r_1, r_2 - radiuses of details edges;

α - corner between a tangent and a plane of an details end face in a point of their contact.

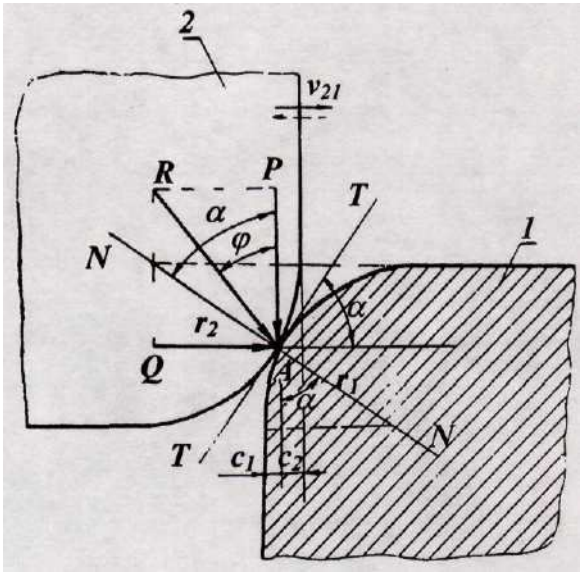

Fig. 3. The scheme of details contact with rounded edges.

The size of the maximal possible overlapping is in dependence from a corner α_{min}, that is from position of a contact point on the detail edges, which in turn depends on a

parity of forces working on a detail, material of contacting details, skew of details in directing assembly adaptations and speed of vibrating moving.

It expands opportunities of automatic connection of details at use of vibrations because the found size with c is commensurable with size of a maximum deviation δ.

Calculation of vibrating movement speed is resulted in view of the forces working on a detail. The maximal speed of vibrating movement

The maximal speed of vibrating movement is

$$v_{x(\max)} = \frac{1}{k_v}\delta_b \sqrt{\frac{2P}{m(r_1 + r_2)(1 - \cos\alpha)}}, \qquad (11)$$

where k_v - the factor of speed determining a parity between the maximal and average speed at various modes of fluctuations and laws of distribution of deviations (in work values of factor k_v for the normal law of distribution are resulted);

$\delta_в$ - maximum deviation in view of overlapping of details edges;

P - force working in a direction of assembly;

m - weight of the details moving under action of force P.

Thus the maximal amplitude of fluctuations is limited to speed of vibrating movement and frequency of the vibrator fluctuations, and minimal amplitude - is limited to size of an error of details relative orientation on an assembly position, i.e.

$$A_{\max} = \frac{1}{2\pi\nu} v_{x(\max)}. \qquad (12)$$

$$A_{min} = \Delta_{\Sigma x} \qquad (13)$$

In promotion work for consideration of the second case of details assembly with rounded edges the design procedure of fluctuations modes is offered in view of the forces working on collected details.

In the **fourth chapter** of promotion work the detail movement on a sine wave trajectory on a site of assembly is considered in view of working forces.

Is solved the equation of a fluctuating detail movement under action of the forces enclosed to it. It is shown, that forces of friction should be taken into account necessarily only at movement of details on a working site of a trajectory, bet the resistance proportional to speed, on this site it is possible to ignore. Displacement of the center of fluctuations from a circle of a rotor due to action of inertia forces in comparison with working amplitudes is changes insignificantly.

The equation is resulted to a standard kind

$$\ddot{x} + p^2 x = -\frac{F_{TP}}{m} sign\,\dot{x} + \frac{F_m}{m}\cos(\omega_F t + \varphi_0)\,, \tag{14}$$

where p - own frequency of a mobile part fluctuations of the assembly adaptation;

F_{TP} - force of friction (total);

m - weight of a mobile part of the assembly adaptation;

F_m - amplitude value of revolting force of the vibrator;

ω_F - frequency of revolting fluctuations;

φ_0 - initial phase of revolting fluctuations.

The decision of the equation (14) is periodic, it is found on stages with a choice of entry conditions of the subsequent value and a final condition of the previous value.

$$x = \frac{F_{TP}}{mp^2}\left[1 - \sec\frac{\pi p}{2\omega_F}\cos\left(pt - \frac{\pi p}{2\omega_F}\right)\right] + \frac{F_m}{m\left(p^2 - \omega_F^2\right)}\cos(\omega_F t + \varphi_0) \tag{15}$$

$$\text{at} \quad 0 \le t \le \frac{T}{2}\,,$$

$$x = -\frac{F_{TP}}{mp^2}\left[1 - \sec\frac{\pi p}{2\omega_F}\cos\left(pt - \frac{3\pi p}{2\omega_F}\right)\right] + \frac{F_m}{m\left(p^2 - \omega_F^2\right)}\cos(\omega_F t + \varphi_0) \tag{16}$$

$$\text{at} \quad \frac{T}{2} \le t \le T\,.$$

Initial phase of revolting fluctuations

$$\varphi_0 = \arcsin\left[-\frac{F_{TP}}{F_m\, p\,\omega_F}\left(p^2 - \omega_F^2\right) tg\,\frac{\pi p}{2\omega_F}\right] \tag{17}$$

and initial displacement of the fluctuating adaptation

$$x_0 = \frac{F_m}{m\left(p^2 - \omega_F^2\right)} \cdot \sqrt{1 - \frac{F_{TP}^2}{F_m^2\, p^2\, \omega_F^2}\left(p^2 - \omega_F^2\right)^2 tg^2\,\frac{\pi p}{2\omega_F}} \tag{18}$$

Conditions of existence of the found decision, i.e. limiting values of resistance forces and assembly force are given also.

The basic conclusions

As a result of the lead researches of process of automatic assembly on rotary automatic devices it is possible to draw the following basic conclusions:

1. Application of vibrating methods for details orientation on the assembly positions expands an opportunity of application of universal assembly automatic devices and allows to lower requirements to accuracy of details manufacturing (on the not interfaced surfaces), acting on automatic assembly. In this case interface is reliably carried out even at a significant divergence of axes.

2. On the basis of research of the vibrating assembly methods, using a various sorts of a trajectory, it is established, that the optimal trajectory of moving of assembled details axes at auto search process is the sine wave trajectory or the trajectory, which is close to a sine wave curve (the minimal time of details connection had been chose as the basic criterion of optimization). The given way of details connection is the simple in realization and besides the sine wave trajectory at chosen settlement and constant for all party, details acting on assembly, parameters covers completely a field of dispersion of deviation of assembled details axes Δ_{Σ}.

3. The method of vibrating assembly used on rotary equipment allows to raise reliability of process of automatic connection of details without toughening requirements to accuracy of their manufacturing and accuracy of units of the automatic assembly equipment.

4. As applied for assembly process on rotary automatic devices the technique of engineering calculation of parameters of a vibrating method of assembly is developed, namely: optimum speed of transport moving and modes of oscillatory movement (speed of oscillatory movement, amplitude, frequency, etc.). The developed design procedure is enough universal and can be used for calculation of other mechanisms and the devices which are carrying out automatic vibrating assembly of details.

5. On the basis of research of friction forces on contacting surfaces the optimum form of edges of interfaced at assembly details is established - it is rounded form of edge.

In work it is shown, that initial contact of details occurs on edges of interfaced surfaces, and that the account of radiuses of rounded edges increases a maximum deviation of details.

6. The corner of a skew of details axes concerning to assembly adaptations changes conditions of initial contact of details and has the maximal value during the initial moment of contact of details. It creates danger of infringement of normal assembly process

and consequently the corner of a skew should be taken into account at definition of boundary conditions of this or that case of assembly.

7. Rigidity of technological system of the assembly automatic device at application of vibrations should conform to size of assembly effort.

At reduction of assembly force (for example, assembly under action of a body weight of details) the force of a clip of a detail should be reduced for preservation of sufficient overlapping edges of details. However it should remain more force of friction arising between contacting face surfaces of fluctuating details. Thus the specified force of friction should be less then the force, created the vibrator.

At increase in assembly force the force of friction on contacting surfaces increases, therefore the amplitude of fluctuations of the vibrator in comparison with initial fluctuations (before contact of details) decreases, that causes danger of infringement of assembly process at the minimal amplitudes.

8. The received settlement dependences and the schedules resulted in promotion work allow at designing the rotary assembly equipment using a vibrating method of assembly, correctly to pick up a drive and to provide optimum modes of fluctuations.

The basic materials of the dissertation are published in the following works:

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