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Experimental investigation of parts vibratory alignment under kinematical excitation

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1. Introduction

Automated assembly requires precisely alignment of the parts in assembly position. Methods and means for interdependent alignment of the parts being assembled considerably depend on parts shape, dimensions, symmetry rank and complexity of orientation motion [1].

One of the most frequently performed assembly operations is peg-hole type parts assembly. Insertion is a process of discretic type, when it is necessary to eliminate existing errors of the parts (components) misalignment, i.e. to align the components to be assembled. It is possible to align the components being assembled providing a peg or a hole with corrective motion. Recently quite a number of new part alignment techniques are introduced and widely applied. Most of the techniques are relatively complex and expensive, since for alignment robot wrists, complex laser positioning systems, information from feedback sensors, neuron net controllers or complex vision systems are used.

Commonly relative part-to-part position error in assembly workspace is characterized by linear and angular axial misalignment. If linear error exists, axis of the peg is perpendicular to the end surface of the bush, and only positioning error exists. Angular misalignment of the axes occurs when axis of the peg is tilted relatively to the axis of the bush. In this case both the positioning and angular errors commonly exist [2].

A method for alignment is known, when one of the components being assembled, i.e. a bush, is vibrated relative to the inserting part in a plane orthogonal to the direction of part insertion, while the peg is incrementally moved in the direction of insertion towards the bush till contact is made with the vibrating edge of the bush hole. Contact of the parts is fixed by the sensors and interdependent position of the parts is adjusted till the parts get aligned and afterwards joined [3]. This method of alignment is rather not efficient and the process of alignment has particular random nature.

In modern engineering sometimes it is necessary to perform automated assembly of the parts having especially small dimensions, therefore various vibratory techniques for parts alignment are applied in more large scale, as miniature parts are passed into assembly position by means of vibrated replaceable elements [4]. In works [5, 6] vibrations are applied to orient automatically the parts of two types. Parts of the first type are passed over pallet and because of vibrations fall into the depressions formed on the pallet.

Vibrating the pallet with plurality of the first type parts, second type parts matingly engage corresponding irregularities in the first type parts by passing the second type parts over the vibrated with different parameters pallet.

This paper analyzes vibratory alignment technique, based on directional matching of connective surfaces of the being assembled components. The directional matching of the surfaces occurs because of initial tilt of the components being assembled relatively one to the other. This tilt is predetermined by nonrigid fixturing of one of the components and applied initial pressing force of interacting components. In order to improve alignment magnetic, pneumatic or other forces should be used. The mentioned means allow achieving directional matching of the parts without position sensors detecting interdependent position of the parts being assembled.

Vibratory matching and assembly of the components is carried out as one of the components to be assembled is subjected to the excitation by low frequency vibrations along the parts joining axis. When vibratory alignment technique is used, there are no strict precision requirements for initial location of the components in assembly position. Reaction forces, arising at the points of part-to-part contact, provide assistance in parts matching.

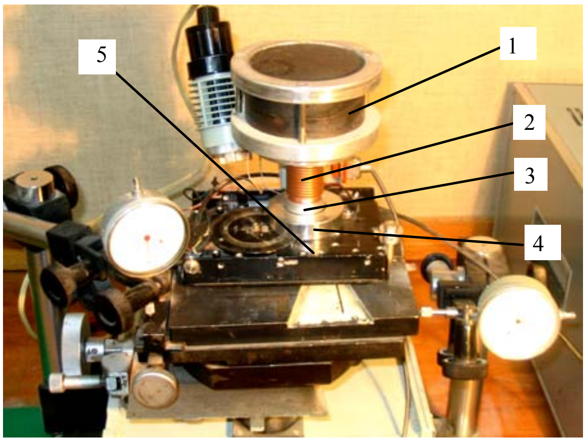
Vibratory part-to-part alignment technique for circular and rectangular cross-section parts being assembled automatically is analyzed in presented paper and verifying experimental data with performed analysis of obtained results are given.

The obtained results of experimental investigation verified that vibratory alignment of peg-hole type components is simple, reliable and inexpensive technique for parts assembly.

2. Experimental setup and investigation method

To perform experimental analysis of parts alignment experimental setup was designed and made (scheme is shown in Fig. 1). Besides the listed elements of experimental setup presented in Fig. 1 low frequency generator, which was used to excite vibrations of the peg along the direction of parts joining, is not shown in the picture. On the surface of locating table a photodiode is mounted (not shown in the experimental setup scheme) used to fix start/end state of component alignment process. Indicators were used to determine both the initial preload force and axial misalignment of the components being aligned. The photodiode via a resistance is connected to oscilloscope, which transforms the analog signal into the digital one. The signal from oscilloscope is transferred to personal computer and using proper software is displayed on the screen of the computer. To clarify interconnection of the mentioned equipment a simplified structural scheme of experimental setup is presented (Fig. 2).

One of the parts to be assembled, i.e. a bush *4*, is immovably fixed on locating table *5*. Peg *3* is attached to resilient element *2*, which is attached to electromagnetic vibrator *1*. Due to existing resilient element being aligned the peg has a possibility to move towards the bush and slightly turn. Experiments were performed using resilient element having the following characteristics: 38 mm length and 28 mm outside diameter metallic bellow, having axial rigidity 0.04 N/mm and the number of bellow coils is 17. It is possible to shift vertically the bellow with the attached electromagnetic vibrator and in such a way to change the force by which the parts to be aligned are pressed. Power circuit is turned on using a switch; power and registration circuits are synchronized. Experiments were performed using peg and hole test-pieces made of aluminium.



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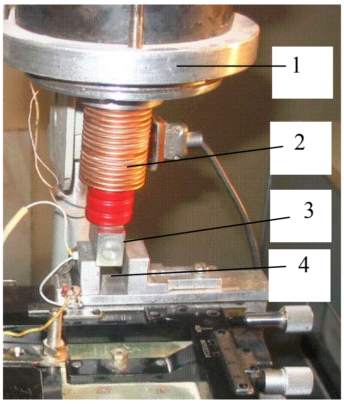


b

Fig. 1 Experimental setup: a – for circular parts alignment, b – for rectangular cross-section parts alignment: *1* - electromagnetic vibrator; *2* - resilient element (metallic bellow); *3* - peg; *4* - bush; *5* - locating table

It is possible to connect peg-hole type parts using various techniques and the main problem here is elimination of parts positioning and angular errors. Very often solution of such type tasks is defined as a problem of the peg directional motion towards the hole of the receiving part (bush) by possibly optimal trajectory. But in presented work the main attention is devoted to parts alignment analysis. The investigation starting from a moment, as the peg contacts with the edge of receiving part (i.e. bush) hole at two points (for circular parts case) or part to part contact by the edge is made (for the parts of rectangular cross-section). Interdependent position of thus contacting parts is determined by error vector, drawn from the center of the peg's bottom surface to the center of the bush hole. Investigated is the influence of the system and excitation parameters on the process of parts alignment.

Applied experimental technique differs from techniques used to solve similar type tasks so, that in this case parts position sensors have not been used. On the locating table, where one of the components being aligned is based, a photodiode is mounted, which purpose is to fix the duration of alignment process, having no influence on the progress of the process. Experiments were performed varying the initial preload, parameters of kinematical excitation and initial axial misalignment of the components being aligned. Part-to-part contact state and intensity of acting contact forces between the peg and the hole is especially important information, when for peg-hole type parts alignment force sensors are used [7].

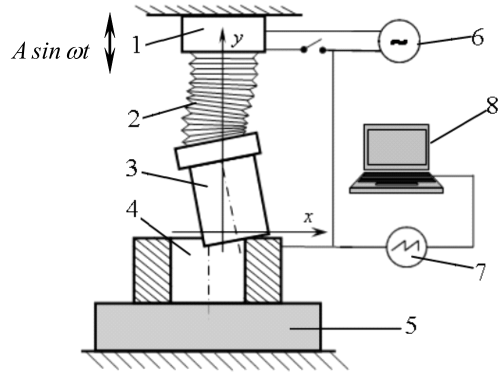


Fig. 2 Structural scheme of experimental setup: *1* - electromagnetic vibrator; *2* - resilient element (metallic bellow); *3* - peg; *4* - bush; *5* - locating table; *6* - generator of low frequency vibrations; *7* - oscilloscope; *8* - personal computer

Part alignment technique, based on kinematical excitation of movably based peg and dynamic properties of two contacting bodies is analyzed in presented paper.

Vibratory alignment of chamferless circular parts and parts having rectangular cross-section was investigated. The experiments were performed trying to align a peg of 29.9 mm diameter in respect of receiving part hole having diameter 30.0 mm. Therefore, cylindrical joint has clearance $c = 0.1$ mm. A peg of rectangular cross-section 15×10 mm was aligned in respect of 15.1 mm width hole opening.

As a performance criterion to evaluate the efficiency of alignment process was chosen time, within which movably based part moves from an initial position to such a position, where connective surfaces of the parts get matched, i.e. the parts get aligned.

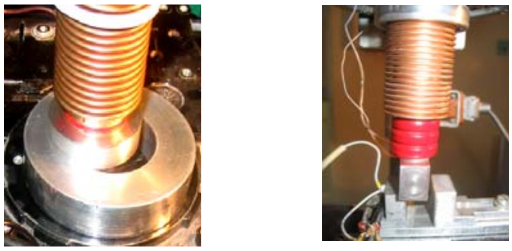
3. Experimental investigation of parts alignment

During experimental investigation the following parameters were varied:

- preload force F from 0.5 to 3 N;
- amplitude A of vibratory excitation from 0.5 to 1.5 mm;

- frequency f of vibratory excitation from 50 to 100 Hz;
- axial misalignment of the components to be aligned Δ from 0.5 up to 2.5 mm.

Initially the peg is pressed downward to the bush by predetermined magnitude force and so axial misalignment of the parts to be aligned is made. Because of resilient element the peg is tilted at a particular angle in respect to the bush axis. Thus, advantageous conditions are made for elastic restoring moment to arise and to match connective surfaces of the parts. Due to measured by means of an indicator axial misalignment of the components being aligned and because of existing initial preload, the peg initially is slightly tilted in respect to the bush (Fig. 3), but this tilt angle was not measured.



a b

Fig. 3 Initial part-to-part position at the beginning of alignment: a – parts of circular cross-section contacting at two points; b – parts of rectangular cross-section, edge contacting

Through the gap between cylindrical components the light from external source freely reaches the photodiode, as the later is not shaded by the peg. After the low frequency generator is turned on (low frequency signal generator G356/1 have been used), axial vibrations along the direction of components joining axis are transferred to the peg. The photodiode via the resistance is connected to Pico ADC 212 oscilloscope, and the later is connected to personal computer. As sufficient light emitted from an external source reaches the photodiode, then the output signal of the later is current. Voltage jump on computer screen indicates the start of alignment process. Kinematically excited peg moves towards the axis of the bush, and the parts get aligned. After the connective surfaces of the parts are matched, the peg shades the photodiode and the light has no possibility to reach the photodiode. Reversed polarity voltage jump indicates ending of the alignment.

By oscilloscope an analog signal is transformed into digital signal and by means of application software is processed on the screen of personal computer. From obtained oscillogram the duration of parts alignment is precisely defined (Fig. 4).

Alignment experiments with the parts of rectangular cross-section were performed using the same experimental setup. The parts to be aligned were fixed and excited in the same manner as during the alignment of circular parts. In this case the photodiode was mounted at a sidewall of the opening. The same resilient element (metallic bellow) as for circular parts alignment has been used.

Using the obtained results of experimental investigation for the parts of circular and rectangular cross-section alignment duration dependencies on excitation frequency (Fig. 5-6), initial pressing force (Fig. 7) and initial axial misalignment of the parts (Fig. 8) were made. In the mentioned graphs mean values of alignment duration obtained from 5-7 attempts were applied.

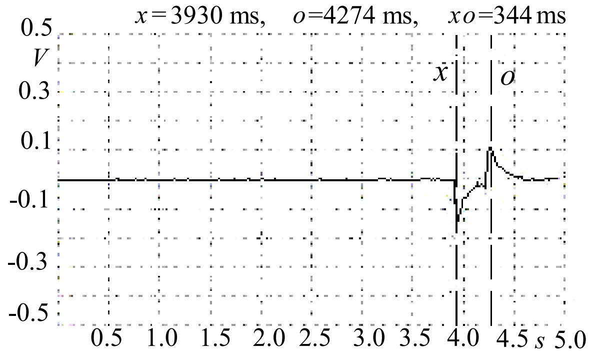
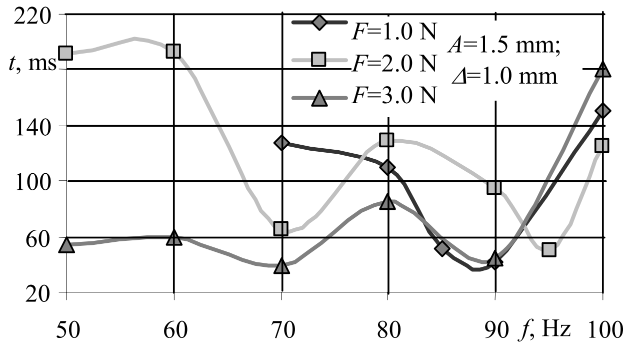


Fig. 4 Experimental oscillogram indicating duration of parts alignment (V–volts, s – seconds)



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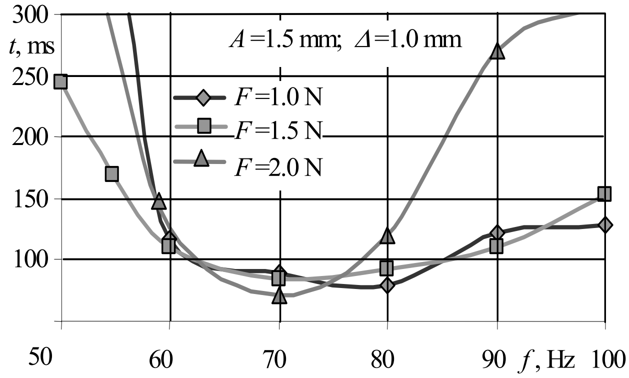


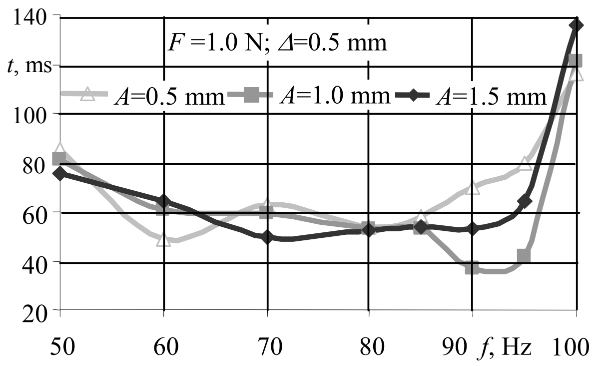
b

Fig. 5 Dependence of alignment duration t on excitation frequency f, under applied different initial pressing force F: a – for the parts of circular cross-section; b – for the parts of rectangular cross-section

Excitation frequency has high influence on duration and reliability of alignment. In frequency range 50 to 60 Hz, under initial pressing force $F = 1$ N (initial pressing force is not large enough to force the peg move towards the hole), the parts of circular cross-section not always get successfully aligned (Fig. 5, a). When excitation frequency is from 70 to 90 Hz and under higher pressing force F (from 2 to 3 N) the peg performs stable translational motion towards the hole axis, the alignment is successful and lasts approximately from 60 to 100 ms. Therefore, it is necessary to match properly the magnitudes of excitation frequency and applied pressing force.

In Fig. 5, b, alignment duration dependencies on the excitation frequency f are given for the parts of rectangular cross-section. For the range of frequencies from 50 to 60 Hz the process is unstable and lasts relatively long time (300 ms to 3 s). Under higher frequencies (60 to 80 Hz), similarly like it was noticed for the alignment of circular cross-section parts, the process is stable and has short duration (approximately 70 ÷ 100 ms). When excitation frequency is equal to 90 Hz and even higher, different vibratory regimes of resilient element and peg attached are taking place and duration of the alignment significantly increases.

The magnitude of the initial pressing force influences not only the tilt angle of movably based component, but also influences duration of the alignment process. It is seen from the given graphical dependences (Fig. 6), that for axial misalignment Δ=0.5 mm, initial pressing force $F = 1$ N, and excitation amplitudes $A = 1$ mm, $A = 1.5$ mm the process is stable and reliable, without failures during parts alignment, and process duration is relatively small (~80 to 150 ms). As the frequency increases (> 90 Hz), alignment duration gets significantly longer.



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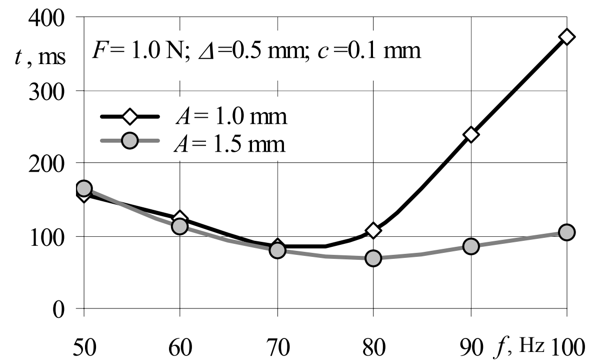
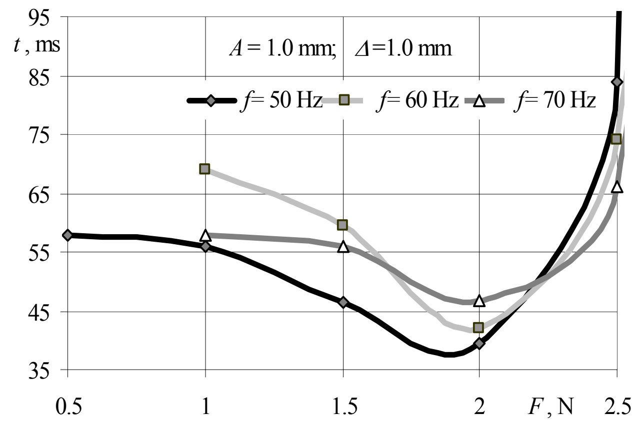


b

Fig. 6 Dependence of alignment duration t on excitation frequency f, under different excitation amplitudes A: a – for the parts of circular cross-section; b – for the parts of rectangular cross-section (where c – joint clearance)

The dependencies of alignment process duration on initial pressing force F for the parts of circular and rectangular cross-sections are different (Fig. 7). Mentioned dependencies for circular parts have minimum, which exist, when applied pressing force is approximately 2 N. As pressing force increases, duration of the alignment also significantly increases. Alignment process gets unstable, because for the same set of excitation and system parameters, the peg does not always get aligned relatively to the bush. Duration of part alignment for rectangular cross-section parts depending on pressing force is increasing, and alignment process gets unstable when higher pressing force is applied.



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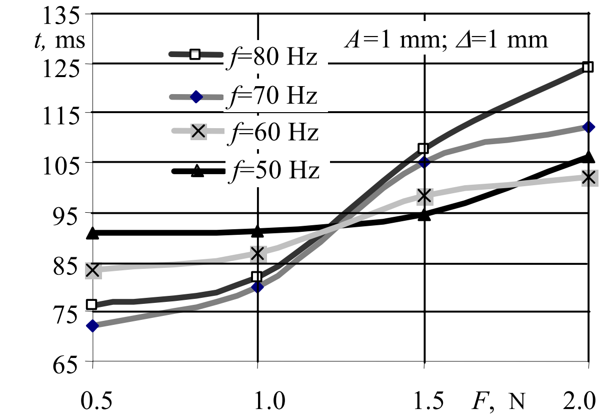

b

Fig. 7 Dependence of alignment duration t on initial pressing force F: a – for the parts of circular cross-section; b – for the parts of rectangular cross-section

Axial misalignment of the parts located in assembly position is predetermined by positioning error of feeding device, e.g. by positioning error of the robot. When low precision robots are used the mentioned error of positioning is up to a few millimeters. As vibratory assembly technique is applied, it is possible easily to compensate this positioning error during the process of alignment. When the error of axial misalignment for the parts of circular cross-section is not exceeding 2.0 mm, duration of parts alignment changes nonsignificantly (Fig. 8, a).

Positioning error higher than 2.0 mm leads to an unstable alignment process, or, under smaller pressing force, the duration of part alignment significantly increases. For parts of rectangular cross-section the duration of alignment within Δ=1.5 mm increases almost proportionally to axial misalignment, but later, as $F \geq 1.5$ N, starts increasing more quickly (Fig. 8, b).

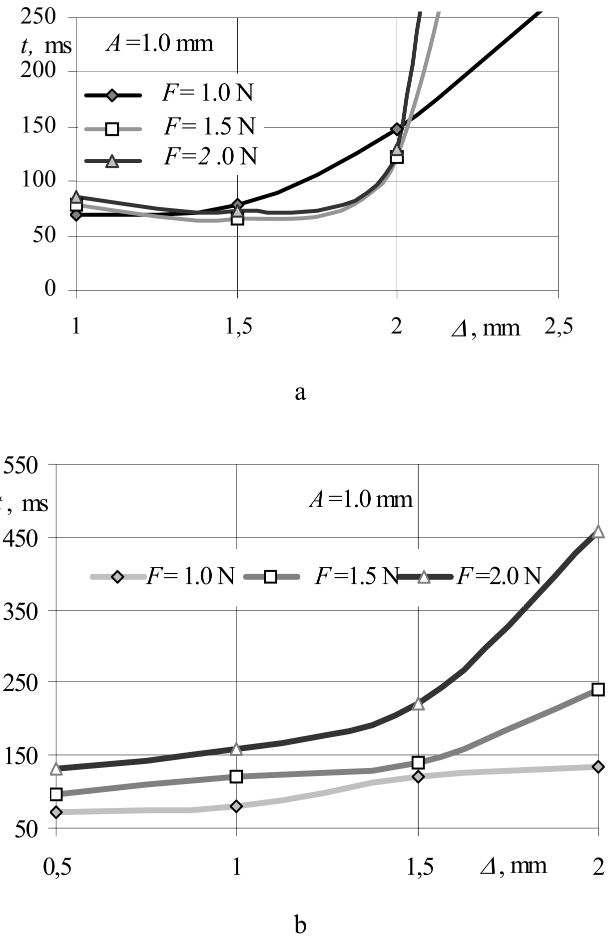

Fig. 8 Dependence of alignment duration t on axial misalignment Δ: a – for the parts of circular cross-section; b - for the parts of rectangular cross- section

It was verified by an experiment that as movably based peg is excited by predetermined frequency and amplitude vibrations, reliable alignment of circular parts and the parts of rectangular cross-section is possible, as positioning error in assembly position is up to a few millimeters. Reliability of the alignment is dependent on rigidity and dimensions of resilient element, which predetermines mobility of the peg, and on initial force of parts pressing.

Based on data obtained from experiments areas of parameters' sets have been determined, where alignment of the parts to be assembled is stable and reliable process (Fig. 9).

When both the amplitude of excitation and initial pressing force are not high enough to force the movably based part move towards the other part to be aligned, the process of alignment gets unstable or is not taking place. To align the parts under higher part-to-part pressing force it is necessary to subject movable based peg to excitation of higher amplitude vibrations.

Performed experimental analysis and obtained results verified that vibratory alignment of the parts to be assembled automatically is inexpensive and simple technique for peg-hole type parts alignment and joining. Having properly defined values of the system and excitation parameters, reliable and fast alignment of circular parts and parts of rectangular cross-section is possible when their positioning error is up to a few millimeters.

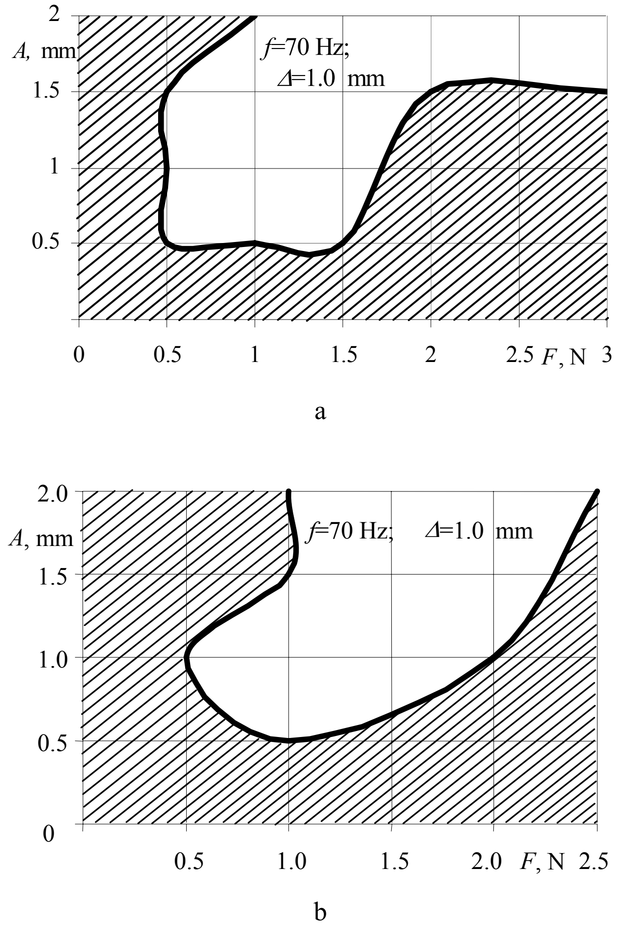

Fig. 9 Area of stable alignment of the parts (unhatched area of the graph) depending on the amplitude of excitation and initial pressing force: a – for the parts of circular cross-section; b – for the parts of rectangular cross-section)

4. Conclusions

1. Experimental data approved that duration of parts vibratory alignment depends on axial misalignment of the parts and magnitude of initial preload force, which is predetermined by rigidity of resilient element.

2. Excitation frequency and amplitude influence both the duration and character of the parts' alignment process. As frequency of vibrations is within the range of 60 to 80 Hz and amplitude of the excitation is from 0.5 to 1.5 mm, alignment of the parts is successful and lasts approximately 70 to 100 ms.

3. At higher excitation frequencies ($f > 90$ Hz) and smaller amplitudes (0.5 mm) unstable and unreliable regimes of vibratory alignment occur, duration of the alignment significantly increases and repeated failures of alignment take place.

4. It was determined, that due to arising parts surface irregularities at the points of contact the process of

alignment may be unstable or even unsuccessful, as not only conditions of parts contact are changing, but also changes direction of resulting reaction force vector.

5. Stability of alignment process is highly influenced by initial pressing force. It is possible to align the parts as initial pressing force is not less than 0.5 N. For stable process of parts alignment the magnitude of initial pressing force is predetermined by the amplitude of kinematical excitation.

6. To perform more comprehensive analysis on the application of vibrations for alignment of the parts to be assembled automatically, it is necessary additionally to perform experimental analysis of part alignment under different conditions of vibratory excitation, i.e. providing excitation along the part insertion direction to the bush fixed in locating table.

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EKSPERIMENTINIS DETALIŲ VIBRACINIO CENTRAVIMO, ESANT KINEMATINIAM ŽADINIMUI, TYRIMAS

R e z i u m ė

Straipsnyje analizuojamas vibracinis automatiškai renkamų detalių centravimas esant kinematiniam žadinimui. Aprašytas eksperimentinis apvalaus ir stačiakampio skerspjūvio detalių centravimo stendas. Pateikti stačiakampio ir apvalaus skerspjūvio detalių be nuožulų centravimo eksperimentų, atliktų esant skirtingiems žadinimo parametrams bei pradinei įvaržai ir skirtingam renkamų detalių ašių nesutapimui, rezultatai. Gauti rezultatai leidžia daryti išvadą, kad vibracinis veleno ir įvorės tipo detalių centravimas ir sujungimas yra paprastas, nebrangus ir patikimas tokių detalių rinkimo būdas.

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EXPERIMENTAL INVESTIGATION OF PARTS VIBRATORY ALIGNMENT UNDER KINEMATICAL EXCITATION

S u m m a r y

Presented paper investigates vibratory alignment and matching of the parts to be assembled automatically. Experimental setups for alignment of the parts having rectangular and circular cross-sections are given. Results obtained performing alignment of circular and rectangular chamferless parts under different both the excitation, initial pressing force and parts misalignment conditions are given.

The obtained experimental results led to the conclusion that vibratory alignment of the parts to be assembled is simple, reliable and inexpensive technique for peg-in-hole operations.

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ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ ВИБРАЦИОННОГО ЦЕНТРИРОВАНИЯ ДЕТАЛЕЙ ПРИ КИНЕМАТИЧЕСКОМ ВОЗБУЖДЕНИИ

Р е з ю м е

В настоящей статье проанализирован вибрационный метод центрирования и сопряжения собираемых компонентов. Представлена экспериментальная установка, которая была использована при экспериментальном исследовании центрирования и сопряжения автоматически собираемых деталей прямоугольного и круглого поперечного сечения. Представлены результаты экспериментального центрирования деталей при разных условиях вибрационного возбуждения, предварительного натяга и разном рассогласовании осей собираемых компонентов.

Полученные результаты позволяют сделать вывод, что исследованный вибрационный метод центрирования и сопряжения является простым, недорогим и надежным методом для сборки деталей типа «вал-втулка».

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