720. Experimental investigation of interference fit connection of mechanical components

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(Received 11 September 2011; accepted 14 February 2012)

Abstract. The experimental setup was mounted, that allows monitoring and analyzing the vibratory connection process of a shaft and the bushing, when they are joined with interference. While changing the parameters of oscillations, the shaft and bushing connection time may be significantly reduced. Increasing the amplitude and frequency of vibrations also allows bigger penetration of the shaft into the bushing. The increase of pressing force allows reliable shaft connection in a wider frequency and amplitude range. It also helps to shorten the insertion time under constant parameters of vibrations.

Keywords: interference fit, vibratory connection, automatic assembly.

Introduction

Interference fit joints are widely used in manufacturing industry, because of a simple manufacturing process, easy design and big application possibilities. The principle of press-fit joining is that the outer part diameter is smaller than inner part diameter. One of the components is acted by axial force and pressed into another part with interference. The parts are moving against each other thus deforming the connecting surfaces until they fully connect. As an alternative to interference fit joints the wedged connections may be also used [1]. The interference forces need to resist joint separation in torsion or tension, depending on the direction of the externally applied loads. Torsion forces act the connected components to slide or rotate along each other, and tension forces act to cause the joint to separate by being pulled or pushed. Sliding or rotation of one joint element relative to another can cause the assembly or structure to come apart.

Most of proposed interference fit researches supposes that the contact conditions are perfect. This is not always happen in reality. The unevenness of joining surfaces and its effect to the connected parts was analyzed experimentally [2]. It was observed that the irregularity of contact surfaces of parts have a big effect on their pressure and a noticeable influence on the fit strength. Experimental investigations were carried out to obtain the characteristics of surface deformations after the parts connect and their effect on the strength of the joint [3, 4].

The connecting parts may be not just cylindrical, but also conical shape. The mechanics of the tapered interference fits was analyzed using the finite element method. An analytical solution was suggested to predict the contact pressure among connecting surfaces [5, 6]. Elastic–plastic analysis was used to make the simulation of material behavior of parts. It was concluded that the analytical solution could be used to determine the pull-out force and loosening-torque with 5–10% error.

The selection of standard manufacturing limits for interference fit joints may be automated using an interactive computer program that allow to check the geometrical and material limitations of connected parts [7]. The mathematical model together with the algorithm was developed for this solution and the computer aided selection methods were compared with existing manual methods.

When components such as bearings or gears are pressed on the shaft the resulting interference causes a big pressure at the contacting surfaces. The size of this pressure is important as many components may crack because of press-fit stress concentrations. The vibrations may be used as a tool to determine press-fit contact pressures and cracks [8]. An interference connection is a surface to surface contact and there are only few air gaps in between. Therefore it is stiff enough to allow a transmission of an ultrasonic wave among the surfaces. The received data helps to identify the cracks of components quickly and in efficient way. However, if the interface between parts is small then the stiffness is also lower, so the ultrasound may be reflected.

Experiments also show other benefits of use of vibrations during connection process. For example the vibrations may help to control dry friction between the connecting surfaces [9]. Modern technologies helps to detect even the smallest vibrations, measure the acceleration of connecting parts and transmit the received data from the sensors directly to the computers using wireless transmission devices [10].

Application of numerical simulation for stress analysis of interference fitted connections gives more complete and accurate results than the traditional method if the using three-dimensional finite-element method. Recent studies of interference fit of connections show that the traditional two-dimensional stress calculation method has some limitations. An improved design method, which utilizes two safety factors, was found. It is providing a new approach for evaluating the quality of interference fits. It also helps to get an advice for interference fit design. The selective assembly method combined with the finite element based method for interference fit design gives an effective approach for achieving more reliable interference-fit connections and more precise assembly with lower manufacturing cost [11].

Interference fit joints play also a great role in medical industry. Cylindrical and tapered interference fits provide a reliable connection method between the human bone and the implant. Press fit connections guarantee the reliability and the long-term stability of dental implants or prosthetic appliances. However, usually big pressing forces or impact loads must be applied to the connecting components, therefore sometimes it is problematic to maintain high power equipment in public sector enterprises, for example hospitals, dental clinics. Vibrations may also help to decrease the necessary pressing force and reduce the insertion duration.

The connection process, when the parts are connected with interference and excited with vibrations is relatively little explored. The aim of this experiment is to examine the influence of oscillation parameters to the process of the press-fit joining of shaft and a bushing, its duration, determine the tendencies of vibratory motion of shaft and its dynamic characteristics.

Experimental setup and the technique of vibratory connection experiment

The experimental setup was mounted for research of vibratory connection of mechanical components. The parts are joined with interference, thus the diameter of shaft is greater than the diameter of the hole in the bushing. The normal pressure and frictional forces occur in the surfaces that resist the relative displacement of connected components. Even though the interference between the parts is very small if to compare with the dimensions of the parts themselves, but still the mechanical joining of parts needs to develop big forces at the interacting surfaces of those parts. Therefore, joining and dismounting of the parts require big forces, so the parts are made of relatively soft material - plastics, so that they can be easily dismantled after the test. The surfaces of connecting parts are ripped off and smoothed during insertion process, so the roughness and unevenness of surfaces is not taken into account in this experiment.

The main components of experimental setup are shown in Fig. 1.

The structural schema of the experimental setup is shown in Fig. 2.

The electromagnetic vibrator *1* is fastened to the frame of experimental setup. The shaft *3* is mounted movably in the direction of connection axis. It is acted downwards by a axial pressing force of the load *5* and slides down into the bushing *2*. The bushing *2* is fastened rigidly to the platform of the electromagnetic vibrator. The shaft slides by length Δ until it touches the platform of vibrator. The contacting area of surfaces is increasing until the shaft penetrates the bushing by its size – the length h. The bushing is excited by harmonic vibrations $A\sin\omega t$ in the direction of the connection axis. The excitation signal is formed by a low frequency signal generator *7* and amplified by amplifier *8*. The movement of the shaft is registered by the shaft position sensor *4*. The data of experiment are processed, compiled and analyzed with computer *8*. The measuring graph of shaft's movement and insertion duration is shown in Fig. 3.

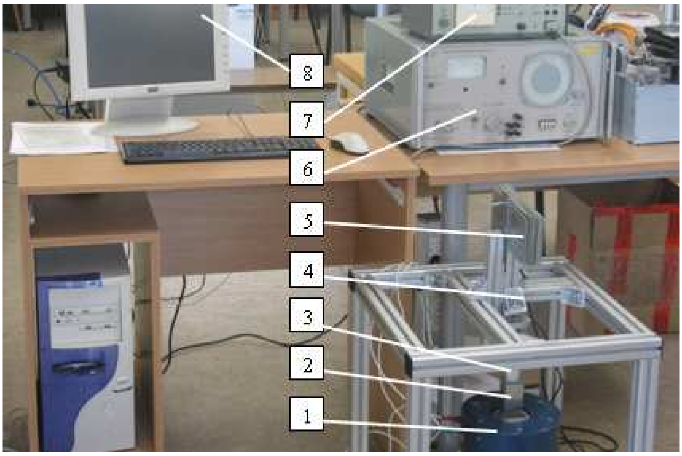

Fig. 1. Vibratory connection experimental setup: *1* – electromagnetic vibrator; *2* - bushing; *3* – shaft; *4* – shaft's position sensor; *5* – load; 6 – signal generator, 7 – amplifier; 8 – computer

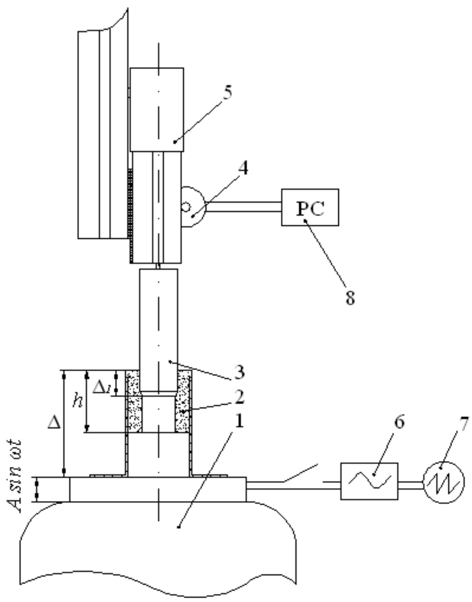

Fig. 2. Structural schema of the experimental setup: *1* – electromagnetic vibrator; *2* – bushing; *3* – shaft; *4* – shaft position sensor; *5* – load; *6* – amplifier; *7* – signal generator; *8* – computer

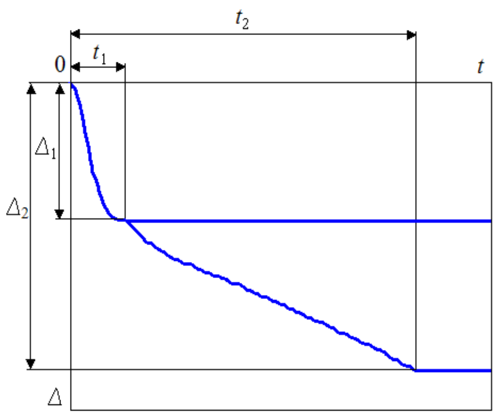

Fig. 3. The graph of the shaft movement in the bushing: Δ_1, t_1 – shaft insertion depth and insertion duration, when the shaft movement is stopped by interference forces; Δ_2, t_2 – shaft insertion depth and insertion duration, when the shaft overcomes the interference forces and touches the platform

Experimental results

Several tests were carried out in order to investigate the regularities of interference fit connection process of mechanical parts. One of the parts is under excitation of different vibrations; another is acted by pressing force until the parts completely connect. Mainly the parameters of vibrations – oscillation amplitude A and oscillation frequency f were varying while the pressing force F and interference values were constant.

The dimensions of the components used in the experiment and other technical characteristics are shown below:

- Shaft - length 100 mm, diameter 30.5 mm, material - plastics;
- Bushing - length 50 mm, hole diameter 29.95 mm, material - plastics;
- The movement of a shaft until it touches the vibrator's platform Δ = 78 mm;
- Pressing force F varies from 45 N up to 105 N;
- Oscillation amplitude A varies from 0.4 mm up to 3.0 mm;
- Oscillation frequency f varies from 40 Hz up to 120 Hz.

The bushing begins to vibrate when the electrical switch connects the excitation circuit. The shaft is acted by pressing force and is moving downwards in respect of the bushing. The pressure on material surfaces and friction forces act as a resistance force, which is opposite to the pressing force. The pressing force F is gradually increased while adding an additional load along the axis of the shaft. The pressing force under defined vibration parameters exceeds the resistance force, and then the shaft is moving by length Δ, until it touches the platform of the electromagnetic vibrator.

The size of friction force is proportional to the contact area of the parts. When the shaft is penetrating into the bushing, it is increasing. However, the bushing has definite height, so after the shaft is joined fully with the bushing, the friction force of surfaces stops to increase and is constant until the shaft touched the platform of vibrator.

However, in the case when the pressing force was smaller than the resistance force, the shaft is inserted into the bushing only by length Δ_1. It vibrates with the bushing, but does not move in respect to it. For example, when shaft is pressed with 45 N force, the amplitude of vibrations is 0.8 mm and frequency of vibrations is 40 Hz, then the penetration of shaft in the bushing is only 26 mm. If frequency is increased to 60 Hz and other conditions are left constant, the penetration of shaft increases to 38 mm in respect to the bushing. The results are shown in Fig. 4.

The results show that the increase of frequency of vibrations has a direct influence on the shaft's penetration depth in the bushing. Higher frequency vibrations also allow connecting the components in shorter time period. For example, if the frequency of vibrations is 100 Hz, then the shaft touches the platform of vibrator after 3.755 s. If the frequency is increased to 120 Hz and other conditions are left constant, then the shaft touched the platform more than two times faster. This can be explained by higher velocity of movement of connecting components and reduction of friction between the contacting surfaces.

Increasing the amplitude of vibration A also shortens the insertion duration and allows bigger penetration. When the amplitude of vibrations is not big enough, the shaft is penetrating into the bushing only by length Δ_1, because the surface compression and friction forces overcome the pressing force of the shaft. The shaft is moving until the platform of vibrator by length Δ only when the values of vibration parameters exceed the minimal values suitable for reliable joining of components. The results are shown in Fig. 5.

When the pressing force is increased, then shaft is moving until the platform faster and the connection duration decreases. However, the pressing force has bigger influence then the amplitude of vibrations is pretty small. When the amplitude of vibrations is exceeding 1.5 mm, then it does not have such big effect on shortening the insertion duration. The received data is shown in Fig. 6.

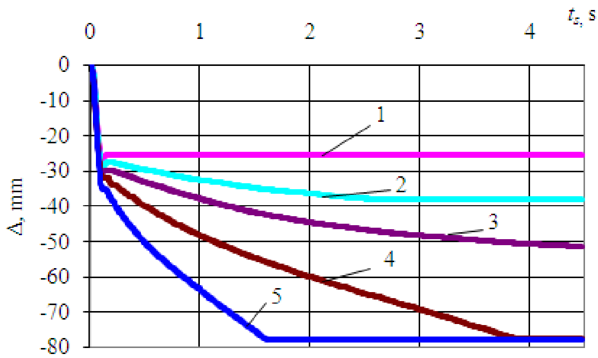

Fig. 4. Shaft's insertion depth *Δ* variation under different vibration frequency *f*, when the pressing force is 45 N and amplitude *A* = 0.8 mm. Frequency: 1 – 40 Hz; 2 - 60 Hz; 3 – 80 Hz; 4 – 100 Hz; 5 – 120 Hz

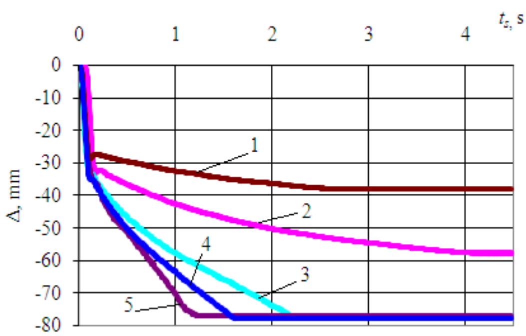

Fig. 5. Shaft's insertion depth Δ variation under different amplitudes of vibrations *A*, when the pressing force is 45 N, frequency *f* – 70 Hz. Amplitude: 1 – 0.4 mm; 2 – 0.6 mm; 3 – 0.8 mm; 4 – 1.0 mm; 5 – 1.2 mm

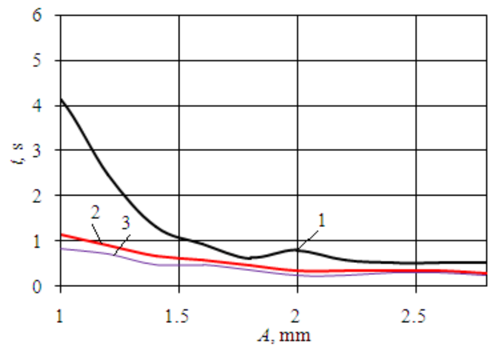

Fig. 6. Shaft's insertion duration t_s variation under different amplitudes of vibrations *A*, when the frequency *f* – 70 Hz. Pressing force: 1 – 45 N; 2 – 65 N; 3 – 85 N

The reliable connection of components may be assured even with smaller pressing force. The bigger pressing force may also result in cracks or deformations of components. The use of vibrations in the connection process helps to decrease a necessary pressing force, therefore, it may be successfully applied in the assembly operations.

Further research is related to the influence of variation of interference of details to the process of shaft insertion in the bushing may be continued. It is also necessary to examine the characteristics of connection, when the parts are excited by transverse vibrations.

Conclusions

During this experiment the experimental setup was mounted, that allows monitoring and analyzing the vibratory connection process of mechanical components, when they are joined with interference. Increasing the amplitude and frequency of vibrations allows bigger penetration of the shaft into the bushing. While changing the parameters of the oscillations, the optimum conditions for connection may be established, and the components are joined with smaller pressing force. The time of connecting the mechanical components may be significantly reduced, if the vibrations are applied to one of the components. It was found that when the bushing was vibrating by 0.8 mm amplitude, the time for shaft insertion was shorter more than twice, if the frequency of vibrations was increased from 100 Hz to 120 Hz. However, the increase of pressing force allows reliable shaft connection in a wider frequency and amplitude range. It also helps to shorten the insertion time under constant parameters of vibrations.

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