A STAND ABOUT COMPLEX RESEARCH OF THE PROCESS OF AUTOMATIC SCREW DRIVING

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Abstract. The assembly process using threading fastening parts includes three stages: "adapting" of the threading parts and subsequent catching, driving the basic part of the thread and subsequent tightening by a definite moment. Various factors influence the gathering of the parts during the automatic screw driving. A part of them is dynamically changed during the screw driving, by the reason of which the process of their research is troubled. In this work is described a device about complex research of the process of automatic screw driving including measuring of the basic parameters influencing the process.

Keywords: automation, screw, stand, research

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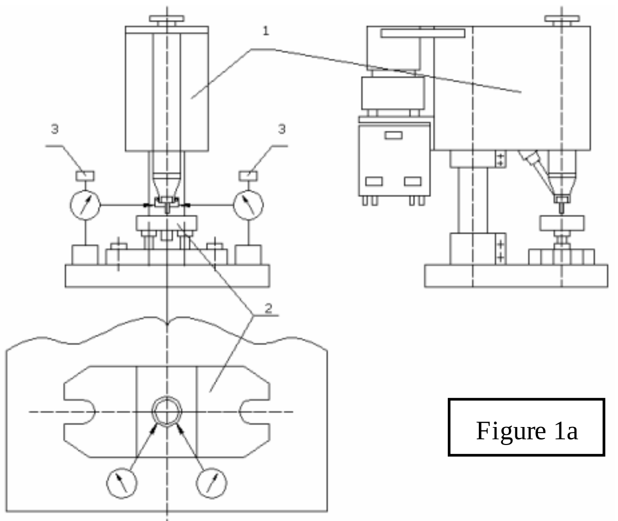
1. Introduction

The assembly process using threading fastening parts consists of several stages. The product parts, which are due to be mounted, are disposed and mutually oriented on the assembly position. Then the threading fastening parts are fed and screwed on. Screwing on includes three stages: "adapting" of the threading parts and subsequent catching; driving of the basic part of the threading and subsequent fastening by a definite moment. Four groups of factors influence the gathering of the parts during the automated screw driving:

- kinematics of the process: the paths and the rates of movement of the initial points of the thread respectively of the screw and the nut, as well as the mutual displacement of the axes of the two parts;
- the geometrical conditions about the gathering and the correctness parameters of the parts, participating in the technological process;
- the influence of the acting forces and the stiffness of the technological system;
- the influence of the arising inertia errors (arising under the influence of the forces of inertia).

2. Structure of the stand and its modifications

The stand is created by the author in the machine-building department in Technical College "John Atanasov" – Plovdiv, figures 1a and 1b. It consists of a combined unit (1) for screw driving AГB-6, completed for the research purposes, a control device (2) for measuring $\Delta\Sigma$ and magnetic stands with micrometer clocks about reading the axes displacement $\beta\Sigma$.



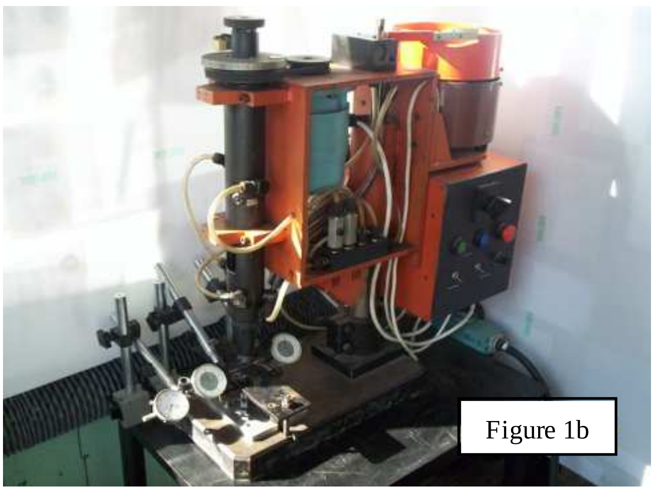


Figure 1. A stand about research of the gathering of screw joints

The screw driving unit, figure 2, is intended for mechanizing and automating of the processes during screwing screws with thread dimensions from M3 to M6 and stem length from 5 to 30 mm. It consists of the following basic elements and meetings: a vibrational hopper ВБ for automatic orientating and feeding the screws, a body in which there are a feed collector for automatic separating and feeding screws, electromotor Д for rotating the tool, belts Ш1 and Ш2 for transferring the movement, bearings Л1 and Л2 for the spindle, cylinder Ц1 for doing the rectilinear movement of the tool, a chuck И for directing the screw to the threading hole and its screwing, Р – a handle and В – a feeding screw for adjustment the height of the position of the Vibrational Feeding Device, an electric panel for managing the technological process, a frame for fixture of the basic elements and meetings, a working table with a T-formed channel for fixing the devices. A stopcock for stopping the flowing out of the air from the outgoing high road and equalizing the pressure between the two areas of the feed air cylinder is added to the pneumatic system of the screw driving device. That will allow the movement of the mechanical screwdriver to be prevented.

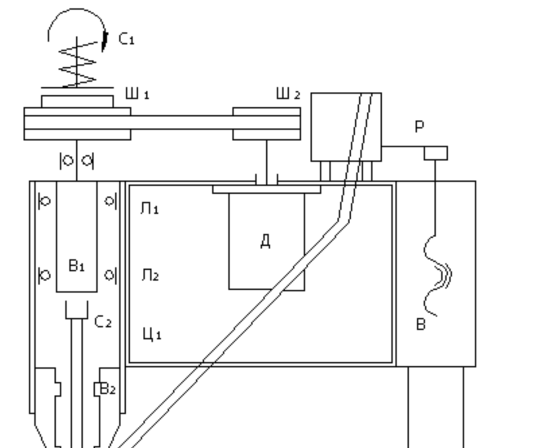


Figure 2. Screw driving unit – kinematic scheme

3. Control Device

The control device about measuring the displacement of the axes imitates an assembling position from a random automatic complex (figure 3). It consists of a lower plate (1) and an upper changeable plate (2), acting the role of a device-satellite with a part which will be screwed. On the lower plate are mounted two founding fingers (3) and (4), mutually perpendicular dial indicators (5) and (6) and the hole (7) is drilled. In the upper plate the thread hole (8) is drilled, which is cylindrical in its lower part where the mandrel (9) is rammed. Before testing, the dial indicators are put on zero according to a changeable control mandrel which is rammed in the hole (7) and caught by the jaws of the tip of the Vibrational Feeding Device. At that position the device is caught hard to the base of the unit. After that the mandrel is pulled out of the hole (7) and consecutively the plates (2) are put to be done the screw driving.

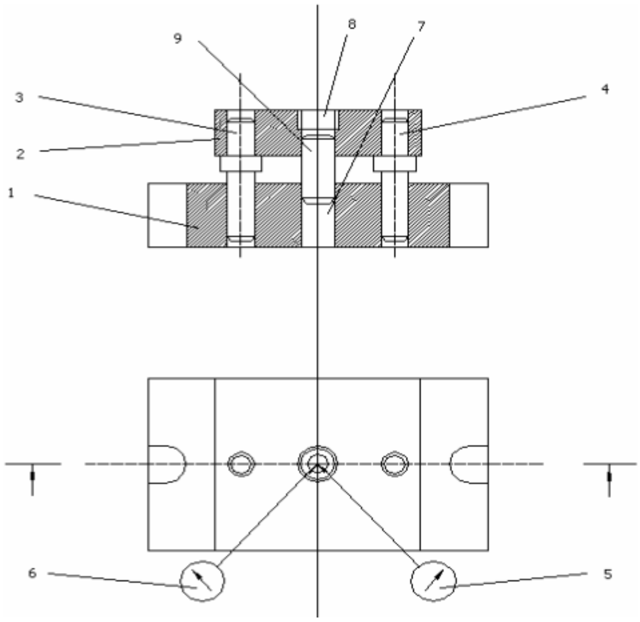


Figure 3. Control device

4. Possibilities for researching various factors influencing the process of automatic screw driving

4.1. Research of the axis displacement between the screw and the nut

The error as a result of displacement between the screw and the nut along the two axes is read on the dial indicators (5) and (6). The actual error is calculated by the following formula:

$$\Delta\Sigma = \sqrt{(\Delta\Sigma_x)^2 + (\Delta\Sigma_y)^2}\ , \qquad (1)$$

where Δx and Δy are the figures of the dial indicators (5) and (6) from figure 3.

The above mentioned way for reading is a possibility of principle for getting the axis displacement of the threading hole on a random device-satellite. That scheme, however, is too slow to be realized an experiment consisting of majority of separate experiments (measurements). In order the process to be accelerated a modification of the stand is created, in which on the fixed fingers is based a device-satellite and the thread hole can be removed easily along any of the axes with the help of micrometer screws. The structure of this modification of the device, shown on figure 4, is:

The control device contains a part, simulating a device-satellite, which is more complicated than the satellite in the basic scheme of the stand. In this modification the satellite consists of two parts – movable and immovable plates. The immovable plate (4) has a rectangular bed (emptying) worked out from the side of the assembly. In it the movable part can be removed along the two axes. In the middle there is a hole big enough to provide free movement of the mandrel with the threading hole (9). On the two sides of the movable plate (1), in the direction of the assembly, are situated screws and nuts intended for removing and fixing the movable plate. The movable part of the device-satellite is a L-formed plate (8) with a hole in its center intended for basing the mandrel and with a bed for the nut. In the L-formed part of the plate always the hand of the dial indicator (6) touches, in order to be measured the displacement along one of the two axes during the experiments. The displacement along the other axis is equal to zero, which saves a lot of calculations.

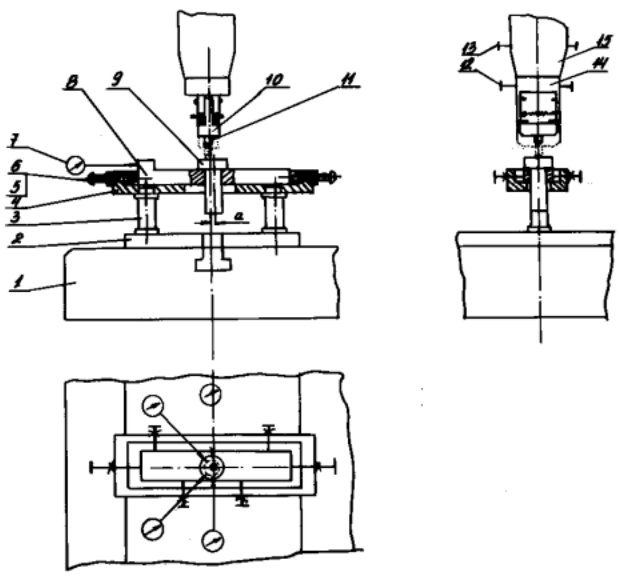


Figure 4. A modification of the stand for research of the axis displacement

4.2. Research of the angle of crossing between the axes of the screw and the thread hole

For measuring the crossing between the axes the dial indicators (3) from figure 1 are used. They are put on the micrometer stands and touch the left and the right chuck jaws of the screw driving unit.

Before starting the measuring, the dial indicators are put on zero towards the jaws and at the same time the mentioned above changeable control mandrel is caught and rammed in the hole (7) of the device. The crossing of the axes between the screw and the hole, in which the screw will be driven, causes displacement of the chuck jaws which is read by the micrometer dial indicators. The method for calculation of the angle of crossing in general as well as in these definite realized experiments is treated in an article devoted to that problem.

4.3. Research of the process of automatic screw driving in different correlations of the rotational speed and the feed speed

The combination between the sizes and the directions of the rotational speed and the feed speed is important about the realizing of the process of automatic screw driving. According to the theoretical research of some authors optimum is such a correlation between the rotational speed and the feed speed in which the total vector of the speed has an inclination in the vertical plane, touching the cylinder on which the screw line is, equal to the inclination of the screw thread. In that case they have in mind the fact that in any other correlations between the two speeds the opening of the screw thread would hit the upper or the lower turn of thread of the hole, which will cause a disadvantageous reaction of the fulcrum in the form of a force which would "throw" the screw from the nut or respectively would wedge it.

5. Rotational Speed

The rotational speed of the spindle in the machine type АГВ6 is a product of engine revolutions and the speed ratio of the belt drive

$$n_{sp.} = N_{eng.} \cdot \frac{d_{p1}}{d_{p2}} = N_{eng.} \cdot i_{s.r.}, \qquad (2)$$

where: d_{p1} is the diameter of the first pulley, d_{p2} – the diameter of the second pulley, $N_{eng.}$ – the engine revolutions of the machine, $i_{s.r.}$ – the speed ratio of the belt drive.

It's obvious from the above formula that the way the rotational speed to be changed is by a change of the speed ratio $i_{s.r.}$ Unfortunately, it's difficult because of the fact that on one of the pulleys the transducer for counting the revolutions is mounted. The other inconvenience is that the dismounting of the pulleys and their replacement by other ones is a slow process which will strongly prolong the duration of the experiment.

6. Feed Speed

The feed speed in Vibrational Feeding Device АГВ-6 is defined by the speed of the piston of the pneumatic cylinder, which runs the chuck with the jaws and the hole to the thread hole. This speed is regulated by a throttle valve – check valve, which is a part of pneumatic scheme of the machine. As in some parts of the cycle the movement of the screwdriver and the chuck is not one and the same, in order to be measured the feed speed the chuck is dismounted and several control feeds of the screwdriver are made to the hole. The time that distance is passed is measured by a chronometer. It must be noticed that the distance h is adjusted and measured in advance.

The speed is calculated as an average value from all the measurements by already known formula about the connection between the speed, the distance and the time:

$$v_{average} = \frac{\sum_{i=1}^{n} h_i}{\sum_{i=1}^{n} t_i} = \frac{h_n}{t_1 + t_2 + \dots t_n} = \frac{n \cdot h}{t_1 + t_2 + t_n}, \qquad (3)$$

where: h is the length of the distance passed by the screwdriver, n – the number of the cycles, t_1, t_2 and t_n – the times measured for passing the distance during the corresponding cycle.

7. Total Speed

Knowing the rotational speed, which in that case is convenient to be permanent, and various feed speeds are given, various total speeds can be got, which are calculated by the formula:

$$V_{t.s.} = \sqrt{(V_{f.s.}^2 + V_{r.s.}^2)}\,. \qquad (4)$$

That gives the opportunity to be done experiments about the influence of the total speed upon the gathering on the stand, as well as about the correlation between the total speed and the rest of the factors influencing the process.

8. Research of the process of automatic screw driving using systems with various number of degrees of the mobility

It's known that to be excluded the negative influence of the axis displacement and axes crossing, the crew and the nut must have additional degrees of the mobility, which number can be different. To be done the problem it's necessary to be given the movable base (as well as the part) minimum two linear travels towards two co-ordinates and two rotations towards the same two co-ordinates. Therefore the minimum number of the additional degrees of the mobility is equal to four. These degrees of the mobility can be divided between the screw and the nut in various ways – to be given to the one part or both of them to be given two degrees of the mobility etc. As the parts must have two more degrees of the mobility which provide them mounting movements, their total number is equal to six. Among the variety of the bases of the threading parts, which can be separated leading by the given degrees of the mobility, there are two extreme varieties. In the first one – only the nut has all six degrees of the mobility, and the screw is based stiffly. In the second one – the screw has the six degrees of the mobility, and the nut is based stiffly. There are a lot of other varieties among the two mentioned. More important for the practice are the following assessments.

The nut is based movably having four degrees of the mobility. The bolt has only technological movements – rotation and translation (two degrees of the mobility). The opposite scheme is also interesting and applicable in the practice – the screw is based movably and the nut has technological movements.

Two more combinations characterize with the fact that the nut, having four degrees of the mobility, which provide error compensation during the relative orientation of the two parts, is given one of the technological movements – the translation. The second combination is just the opposite – the screw is based movably and is rotating, while the nut is based stiffly and has the translation.

There are systems in which both parts are based movably. For example, the nut has two degrees of the mobility, moving along two co-ordinate axes, and the screw can be turned around them as the technological movements can be divided between the screw and the nut in different way.

If the two assembled parts are based next to stiff supports, the screw has the possibility only for rotation and translation and the nut hasn't any degrees of the mobility. That mounting is also known as mounting without correcting effects. Some of the most spread variants of base are schematic given on figure 5. It's seen from the classification that the basic variants of screw driving systems according to the way of base are four:

- movable screw – movable nut (hole);
- stiff screw – movable nut (hole);
- movable screw – stiff nut (hole);
- stiff screw – stiff nut (hole).

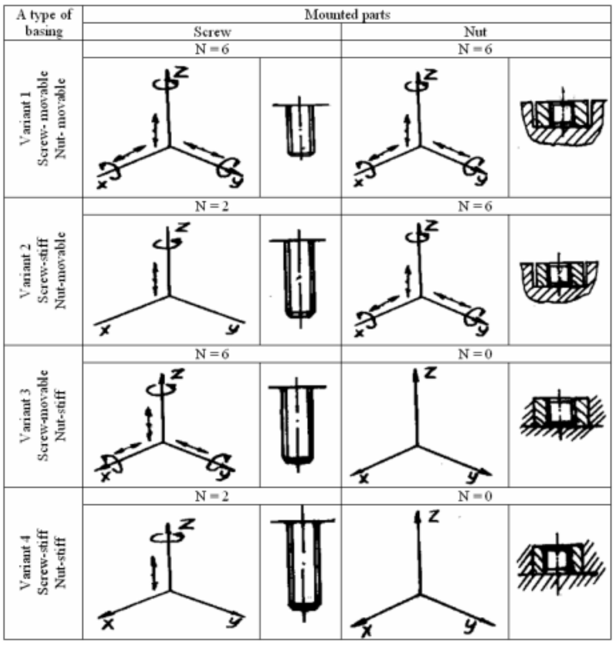


Figure 5. Classification of the variants depending on the number of the degrees of the mobility

Realization of the various kinds of mounting systems on the stand is done by replacement of some constructive elements from the screw driving unit AΓB-6 and the device.

The construction of the Vibrational Feeding Device AΓB-6 includes a mechanical screw driver 200 mm long and 10 mm diameter, which thanks to the natural disbalance has a deflection at the lower part of the screw driver, which increases from zero to 0,40 mm during the growing of the speed inside the limits of the cycle. The approximate trajectory of that searching movement is a spiral with gradually increasing radius. By friction with a bush the searching movement is transferred to the part on which the jaws, supporting the screw before mounting, are mounted. Thus the screw together with the screw driver and the jaws, in which the screw is based, are doing oscillatory searching movement before the assembly process. In order to be done a comparison between an assembly with searching movement and such one without searching, a part supporting the jaws is constructed, which can have two positions: in the first one at the expense of a windage it transfers the searching movement and vibrates together with the mechanical screw driver, and in the second one it restricts the movement and the assembly is done without searching. Also new jaws are produced towards which the screw is based without any windage. Thus when the searching movement is done the screw is moving together with the part, on which the jaws are mounted.

The construction of the control device is already described. It contains a part, simulating a device-satellite as the plate with the thread hole can move along the two axes thanks to regulating screws. In that case the thread hole is simulated by a nut disposed in a profile nest having one and the same axis with the pin towards which the linear deflection is measured.

When a system “movable thread hole” is simulated the nut is freely put in the profile nest (bed), produced with a total windage to 0.3 mm. Thus during the process of relative co-ordination the nut can move freely along the two axes in the limits of the bed and to do limited rotations around various axes under the influence of the friction forces between it and the screw. Because of its small table and limited dimensions the nut is comparatively easily moved by the vibrating screw driver and it’s an appropriate object for studying of the assembly in the presence of searching movements.

When a system “stiff thread hole” is simulated the nut is put in a bed constructed on the principle of “terminal joint”, which, when is tightened, deprives the nut of any mobility towards the device-satellite, figure 6.

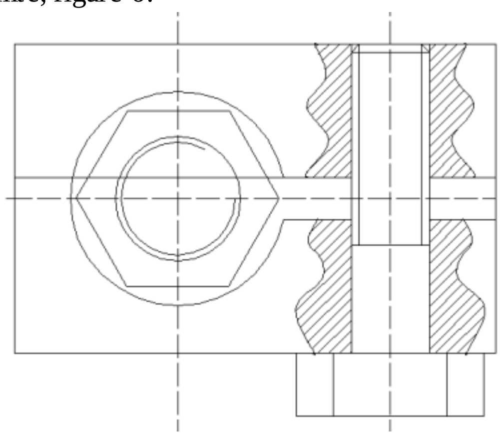


Figure 6. Simulating a system “stiff thread hole” by terminal joint tightening the nut

That gives the opportunity to be researched the behavior of the system, in which the thread hole is completely immovable.

9. Possibilities for researching the influence of the degrees of the mobility of the device-satellite

A known fact from the theory and the practice of the automation of the assembly in the engineering is that in all the assembly complexes, which use transport systems in batch production, the basic part is moved between the separate working places on a device-satellite. It's a traditional concept that the advantages of that approach consist in the possibilities for batch production of the transport system and following that higher quality of production and precision of the carrying out. The presence of a windage between the device-satellite and the fixers of the transport system is considered to be an additional error which is summed with the error of the other parts participating in the assembly process and it makes difficult its effective passing. The presence of a windage, except a technological error, also means one more section in the complex assembling mechanism for screw driving (about which Yahimovich is speaking) having its own additional degrees of the mobility. A question arises if they can be useful or not for the process of automatic screw driving. To be answered that question to already known scheme of the stand for researching the process a heaver-screw tightening device is added, which consists of two screw tightening devices with parallel operation and a plate (heaver), which makes contact with the device-satellite by its face side as it makes it entirely immovable. In the plate is bored a hole whose dimensions are such which aren't obstacles for the process of assembling of the screw and the thread hole.

Thus, that modification of the stand gives the opportunity the influence of the device-satellite to be eliminated and the results in reference to the gathering, when there are degrees of the mobility of the satellite and in the case when those degrees of the mobility are absent, to be compared.

10. Researching the process during working with various kinds of screws and nuts

The screw, as an object of the assembling process, strongly influences the percent of correctly assembled parts. From that point of view it's interesting to be known which elements, surfaces, dimensions, deflections of the shape and the dimensions and in what way they influence the process of automatic screw driving. That question can be made clear if the stand about researching the process has the opportunity to work by various screws.

According to the catalogue of the screw driving unit АГВ-6, it has the opportunity to screw standard screws with different diameters – from 3 to 6 mm. The admissible length of the stem varies from 5 to 30 mm. The moment of tightening varies from 0.5 to 5 N·m.

As it's obvious in the limits of the machine possibilities experiments can be done with screws with various lengths of the stem, various diameters, various screw heads, various surfaces for passing the moment of rotation from the screw driver to the screw, additional centering elements, various ends of the screw etc.

11. Conclusions

- A stand about researching the gathering of screw joints is constructed, as well as its modifications intended to making easier the research in particular cases;
- The possibilities are depicted and methods are created for researching various particular factors influencing the process of automatic screw driving:
  - the axis displacement between the screw and the thread hole
  - the angle of the axes crossing between the screw and the thread hole
  - the correlation of the rotational speed and the feed speeds
  - using systems with various number of the degrees of the mobility of the screw and the hole
  - the influence of the degrees of the mobility of the device-satellite
  - operating with various kinds of screws and thread holes.

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