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The drives synchronization system for laser-mechanical pipe bending equipment

System synchronizacji napędów urządzenia do laserowo-mechanicznego gięcia rur

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The drives control system of bending equipment for thinwalled pipes has been presented. The design of the mechanical system was presented and the control system was briefly characterized. The advantages and disadvantages of the presented solution are discussed. Possible modifications of the system have been proposed in order to improve its functionality.

KEYWORDS: laser forming, laser technologies, control systems

Laser forming is classified as one of the methods of thermal forming of structural elements. During this process, deformations arise due to the phenomenon of thermal expansion of the material [1-3].

Adequate and controlled heating of selected material zones by the laser beam causes it to assume the assumed shape. Despite the many advantages of laser forming, this process is energy-intensive and runs relatively slowly compared to classical methods (e.g. plastic shaping).

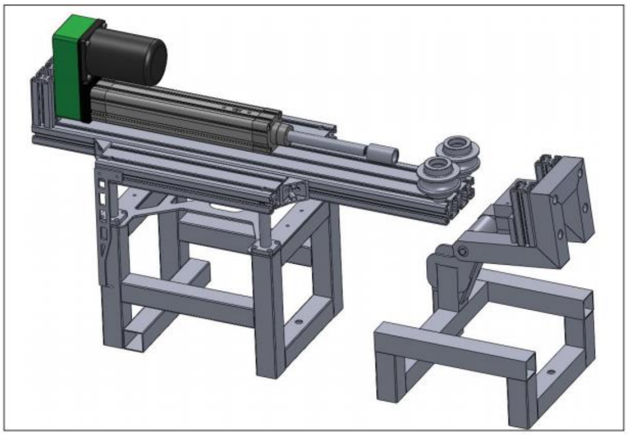

Fig. 1. Device design [4]

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Due to these limitations, research was undertaken to develop a hybrid shaping technology, consisting in heating the bent element with a laser beam with simultaneous mechanical support [4]. For the purpose of this task, a special device was developed and made (fig.1), which was integrated with the TRUMPF TLF 6000 laser machining center.

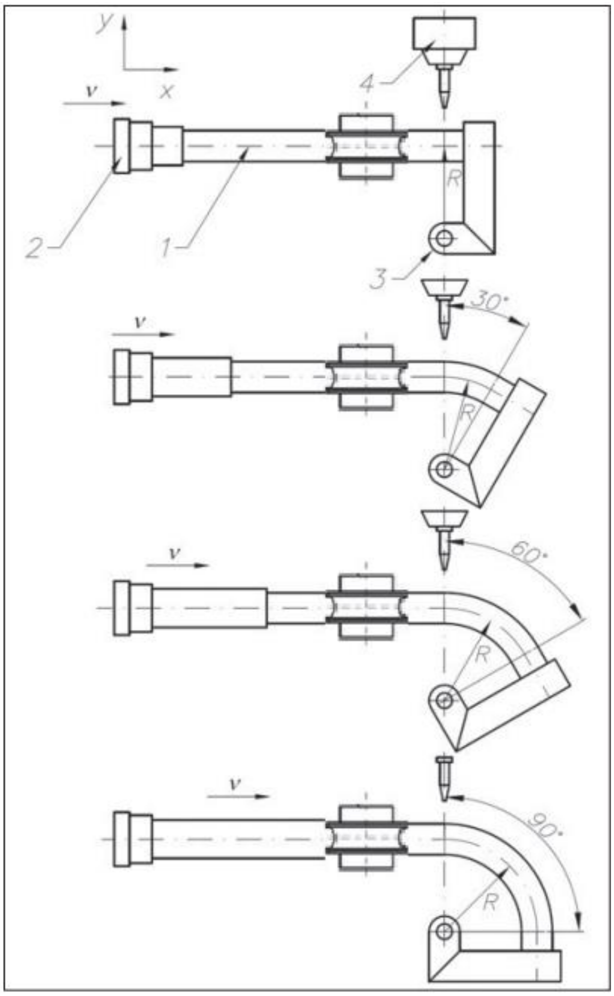

Fig. 2. Kinematics of the bending process: 1 - tubular element subject to bending, 2 - pushing actuator, 3 - free bending arm, 4 - laser head [4]

Principles of device operation

The device is designed for mechanically assisted, single-plane laser shaping of thin-walled tubes. The kinematics of the bending process is shown in fig. 2. The device is driven by a linear electric drive (consisting of a motor and gear), hereinafter referred to as an actuator.

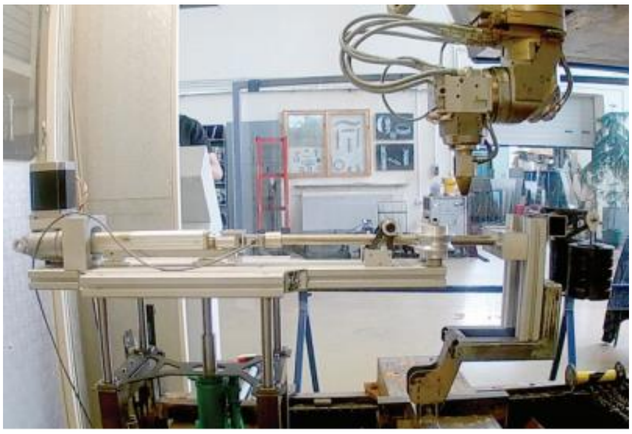

Fig. 3. Working part of the station [4]

According to the developed concept, the bent element (1) is placed between the actuator (2) and the free bending arm (3). The laser head (4) peripherally heats the element in the bending plane. At the same time, the cylinder rod is extended along the *X* axis and the bent element is put into linear motion. The end of this element is attached to the holder located on the bending arm. The arm has one degree of freedom (the ability to rotate around the *Z* axis of the coordinate system). The bending radius *R* is determined by the dimension of the bending arm and the distance of its pivot from the axis of the bent tube. The piston rod of the actuator is equipped with a force transducer to determine the forces achieved during the bending process. A digital inclinometer was installed on the bending arm to measure the obtained bending angle.

Fig. 4. Device control systems

In order to ensure the precision of the bending process, a device control system has been developed that allows controlling the actuator's extension to a given distance with a specified speed of movement. The linear actuator drive is an induction motor controlled indirectly by the frequency inverter. The control system is based on the MyRio-1900 controller, which uses a real time RT system with a frequency of 1000 Hz. The system uses a classic speed controller with the PI algorithm. The feedback signal for the control system comes from the incremental rotary-pulse transducer mounted on the motor shaft with a resolution of 1024 pulses/revolution. The developed control system makes it possible to force the movement of the actuator's piston rod with a given feed in the range of 0÷400 mm/min, and also to carry out the piston rod homing procedure and reset its current position in any position. The system has been protected by contact limit switches, which prevent excessive extension or retraction of the piston rod. The system allows you to observe the force and bending angle in real time in the LabView environment. The stand is shown in fig. 3 and fig. 4.

Problems encountered

During the operation of the device, it was found that it works correctly, which allows the implementation of the developed hybrid technology. It was observed that during the process of tube bending to an angle not exceeding 45°, the device does not exhibit any dysfunction or disturbing behavior, and the bending process proceeds correctly. However, when bending pipes to an angle in the range of 45÷90°, a gradual increase in force recorded on the actuator's piston in the direction of extension, and at the same time a gradual elastic deflection of the fastening along the *Y* axis. These phenomena intensified after exceeding the angle of bending 45° and while reducing the bending radius. This was due to a change in the distribution of the components of the force exerted by the cylinder piston. In order to eliminate these effects, a new device concept has been developed.

System with drive synchronization

As a method of eliminating the observed undesirable phenomena, it was proposed to use a second drive forcing the rotating arm to rotate. As a drive, a linear actuator with electric drive was used. The concept of the modified position is shown in fig. 5.

According to the drawing, the movement of the bending arm will be forced by the simultaneous movement of both actuators. However, there arises the problem of mutual synchronization of the motion of these drives [5, 6].

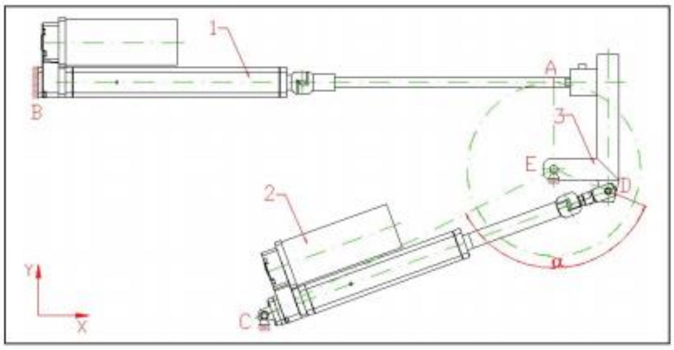

Fig. 5. Modified version of the device: 1 - first actuator, 2 - second actuator, 3 - bending arm

Lack of synchronization could cause incorrect operation of the device and, consequently, even damage of the elements of the structure. According to the developed concept, the movement of the actuators is to be realized with the use of stepper motors. In order to control them, two signals should be generated for each of the drives. The DIR signal is responsible for the selection of the direction of rotation, and the STEP signal - for determining the rotational speed. The number of generated STEP signal impulses determines the angular displacement of the drive shaft. It should be noted that according to the adopted concept, the speed of extension of the piston rod of the first actuator is fixed and defined by the user. The speed of the second actuator will be variable during the process. It is therefore necessary to designate STEP signals for both actuators and for each moment of pulse of the main loop of the program before starting the system or in real time.

The procedure for determining the control signals for the actuators of the cylinders was started from the determination of the course of changes in the position and speed of the piston rods of the cylinders. Based on the desired process parameters - such as feed and bending angle - the total displacement of the piston rod of the first actuator x_1 and the total movement time t were calculated:

$$x_1 = \phi \cdot R \tag{1}$$

$$t = \frac{x_1}{V} \tag{2}$$

where: φ - bending angle, R - bending radius, V - feed.

Using the iterative methods, displacement values of the first actuator were determined for the total time of movement with a step d_t of 0.001 s - a displacement signal was obtained at time $x(t)$. The speed of movement of the first actuator is consistent with the feed rate set by the user.

The displacement of the second actuator is related to the displacement of the first actuator by trigonometric relations resulting from the rotational movement of the bending arm. According to fig. 5, a triangle with CDE vertices can be determined, with an angle α between the arms CE and ED. In the initial position of the process, the measure of this angle is 131°, and then this angle is reduced by the current value of the bending angle. The extending of the second actuator x_2 can therefore be determined using the cosine theorem:

$$x_2 = |CD| = \sqrt{|CE|^2 + |ED|^2 - 2|CE| \cdot |ED| \cos\alpha} \tag{3}$$

where: $\alpha = (131° - \varphi)$.

After substituting $\varphi(t) = x_1(t)/R$, the formula (3) has the form:

$$x_2(t) = \sqrt{|CE|^2 + |ED|^2 - 2|CE| \cdot |ED| \cos(131 - \frac{x_1(t)}{R})} \tag{4}$$

Using the relationship (4), the course of changes in the position of the second actuator for the total time of movement was determined. The course obtained was differentiated sequentially with a time step of 0.001 s and in this way the course of the speed changes of the second actuator was obtained. The system of calculation of control signals, data acquisition and visualization of force waveforms and bending angle was built using the LabView environment.

Sample runs of preset displacements and speeds of synchronized drives for 90° bending angle and 2 mm/s feedrate are shown in fig. 6.

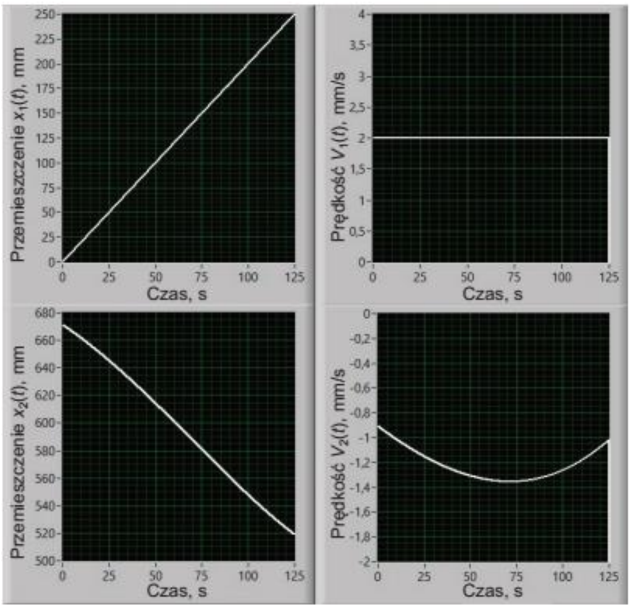

Fig. 6. Trajectories of displacements and speed of drives

Conclusions

The proposed method of synchronization consists in controlling two drives using control signals, determined on the basis of the kinematic analysis of the station. Testing of other devices has shown that due to the lack of additive regulation errors, this method is more effective than the Master-Slave control, in which the second drive is controlled based on the displacement of the first drive. An advantage of the proposed method are simple relationships describing control signals, which makes it easy to implement and allows for a short calculation time.

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