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Robotic Gripping Device for Garment Handling Operations and Its Adaptive Control

Abstract
A pick-up device with flexible drive linkage for textiles is presented in this article. The adaptive pick-up device for textile is based on a drive linkage with flexible links and gripping elements. The paper presents the construction of the robot's pick-up device for textile, the method of making it reliable and the algorithm of its control. The method is based on determining the forces appearing in structural elements under the effect of grippers, and using this data-controlling signal garment handling operation under industrial conditions.

Key words: *robot, pick-up device, gripper, sensor, garment.*

Introduction

Special mechanical systems, such as manipulators and industrial robots, are used in order to automate technological processes in industry. They perform some relatively simple but time-consuming manufacturing and auxiliary operations of automatic technical equipment. Industrial robots are broadly used in the clock, electronic, and automobile industry. They are integrated into flexible production systems. For various objective and subjective reasons, robots have been introduced into the textile industry only recently.

Auxiliary and preparatory operations require 70% of the total production time, while sewing 30% of that time, when sewing garments at a rate of 3000-6000 stitches per minute. A period of auxiliary operations increases relatively by increasing the sewing speed to 8000+ stitches per minute, but the increase in sewing productivity is negligible. In this case, a sewing machine operator physically cannot make auxiliary and preparatory operations at the required speed, and so slows down the whole garment production process [1].

The sewing efficiency depends on both high-speed sewing machines and the duration of manually executed operations and handling. Usually textile pieces that should be sewn together are handled by a worker. Handling includes picking up, conveying, fixing, stretching, and so on. Due to subjective reasons such as experience, working conditions, fatigue and others, the efficiency of auxiliary operations also depends on the size of the pieces being sewn, the properties of their fabric (structure, thickness, stiffness, density, piling, etc.), gripping conditions, the way they are handled, and transportation direction.

Application of grippers in the sewing industry

In today's textile industry, robots are widely used together with the universal and specialised technical equipment [2-5]. The application of industrial robots has resulted in an average increase in labour efficiency of 20% (and for sewing trousers, even as much as 420%) and an improved quality of products [1].

Industrial robots are used in the auxiliary and main technological processes.
Industrial manipulators which perform auxiliary operations can be divided into three groups. The first groupperforms the auxiliary operations prior to the sewing process. They collect, mark, put on the right track, and stack textile pieces in the working zone of an automatic sewing machine. The second group, sometimes called technological sewing robots, work in synchronisation with sewing machines. They grip textile pieces, convey them along a required trajectory within the working zone of the automatic sewing machine, and supervise the distance between the needle and the edge of a textile piece, the number of stitches, their size and other technological parameters. The third group of manipulators puts the sewn pieces or garments on ironing presses or tables, removes semi-manufactured products, folds & packs them, and loads them into the cases.

Industrial robots have also come into use in the main technological processes [6-7]. Various heads for cutting, marking, sewing, ironing, and other special operations are attached to their output links. Sometimes technological heads are installed in a gripper. In such cases, some operations can be carried out at the same time as textile pieces or half-finished products are being conveyed, i.e. it is possible to mark textile pieces during the picking-up and conveying operations.

A gripper is a working device of the manipulator which picks up and transfers the object to be manipulated. It has to grip a textile piece reliably and position it accurately without causing any harm to the textile piece. The construction of such a gripper is quite complex, and its price can amount to 5-10% of the entire manipulator's price [7].

The gripper must meet strict requirements in the textile industry, where extremely pliant (flexible) textile pieces are treated. It must be reliable, high-speed, sensitive, and very accurate, so it can separate pieces of textile cloth one after another from a multilayer stack without damaging them. The gripper must work with uniform reliability during the whole operating cycle, i.e., when gripping a textile piece, separating it from the rest of the stack, handling and placing it; whereas any switch of textile pieces at any stage of the technological process may damage the entire series of production.

Because the shapes and properties of the textile product can vary widely, the construction of the gripper must also be different, in order to meet the various requirements [8-11]. It is impossible to design a single universal and reliable gripper that would be capable of gripping and transferring thin, thick, piling, nonwoven, knit-wear, leather and other kinds of textile. Each technological operation must have its own specialised gripper, which must reliably grip a thin textile piece and detach it from other textile pieces or their layers.

Analysis of textile industry grippers has shown that according to the piece gripping principle, most of them can be divided into five groups: mechanical, pneumatic, adhesive, electrostatic, and magnetic. Several different principles of gripping and separating pieces have been applied in the same gripper, in order to increase the reliability of a textile grip. Mechanical textile piece grippers are most popular for their simple construction and reliability.

Needle grippers are very good for gripping textile pieces. Their structure is quite simple, and they grip a textile piece very well, position it accurately enough and leave no traces on it. It is in fact the most popular gripper construction used in light industry.

The gripping elements of needle grippers are various needles which can be classified as stiff or flexible.

Stiff gripping elements do not deform; however, a textile piece or special compensating elements contained in the holder may deform during the gripping operation.

Flexible gripping elements are deformed by special deformation elements, or may be deformed when touching the piece to be gripped, as their relative stiffness is considerably lower than that of the textile piece being gripped.

Gripping elements are fastened in their holders individually, by pairs, by rows, or groups making an entire needle coating.

Gripping elements are fastened in a holder perpendicular or inclined to its surface. The holders of these gripping elements may be stiff or flexible.

The interaction between the gripping elements and textile pieces depends on the properties of gripping elements, their design, and their allocation in the holder.

Grippers may have no drive (they pick up a piece due to the influence of the piece itself, or that of special elements situated in the manipulation zone) or they can have electromechanical, pneumatic, hydraulic, spring, vibro-transforming etc. drives. The type of gripper drive is determined by the number of mobility degrees, the type of coordinates, the control method, and the control algorithm of the manipulator in which it is installed. Electric drives are especially promising. Compared with other drives, they distinguish themselves as high-speed, reliable, quiet, compact, flexibly controlled, and easily mounted & adjusted. Such drives can make any motion and can be controlled in an adaptive and optimal way. In addition, electric drives can be controlled by centralised means, and so a group of robots, or technological equipment and an industrial complex of robots, can be controlled [12-18]. The problems of constructional and technological compatibility of robots, grippers, and technological equipment are easily solved. The gripper drive type usually corresponds to the manipulator where it is installed, and to the drive type if there are no special technological requirements.

Construction

An adaptive pick-up device for textiles based on a drive linkage with flexible links and gripping elements is presented. The device can be used in technological operations in the sewing industry for the preparation of cuttings. The pick-up device (Figure 1) is installed in the manipulator arm of the industrial robot. This kind of device is more complicated and expensive in comparison with first-generation devices, but needs no additional units for manipulation, storing, orientating or other special devices. The proposed pick-up device is self-adapting to the objects being manipulated, and is especially handy for application in flexible production lines.

The construction of the textile piece gripper is given in Figure 1. It has an individual drive with a linkage mechanism containing flexible gripping elements. Figure 2 shows a textile piece gripper positioned above a stack of cut textile pieces. It is installed in the industrial manipulator gripper (1). On the upper part of the gripper housing (2) there is a drive (3) with an axis (4) and a cam (5) on it. The cam is fastened (fixed on the axis) and installed into the holder (6). The holder is connected to with the housing by elastic links (springs) (7) coupled to hooks (8 and 9) which are attached to the holder and the housing respectively. Sensitive elements (sensors) (10) are installed in the bottom part of the holder, where gripping elements (flexible needles) (11) are fixed with their lower ends

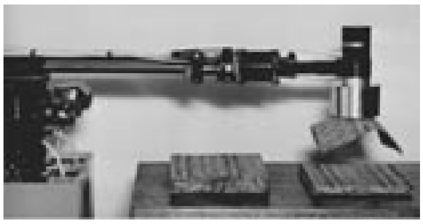

Figure 1. *Robotized pick up-device for textile pieces.*

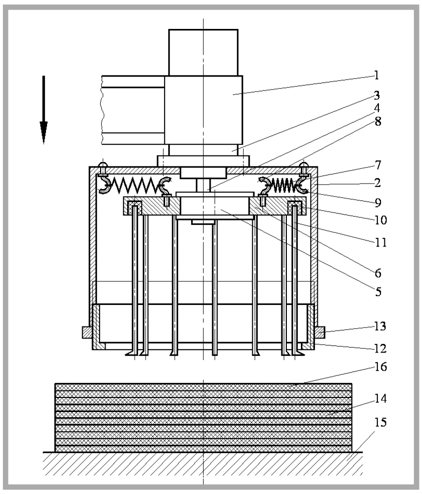

Figure 2. *Gripper for textile pieces positioned over the stack of cut textile pieces; 1 - industrial manipulator gripper, 2 - housing, 3 - drive, 4 - axis, 5 - cam, 6 - holder, 7 - sprinks, 8, 9 - hooks, 10 - sensor, 11 - flexible needles, 12 - limiter, 13 - flowing ring, 14 - stack of textile pieces, 15 - flat base, upper piece.*

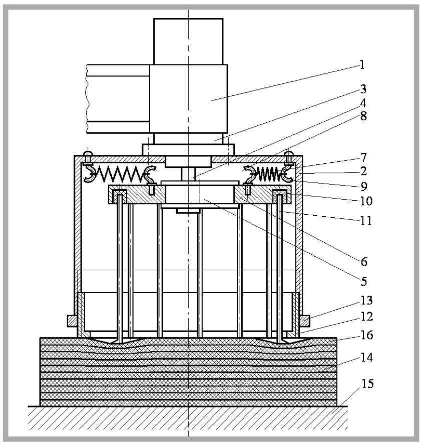

Figure 3. *Gripper of textile pieces lowered on the stack of cut textile pieces; all indications as in Figure 2.*

bent and sharpened. A limiter (12) with the fixing ring (13) screwed on it is on the bottom of the housing.

The stack of cut textile pieces (14) lies on the flat base (15), and the gripper is oriented so that the axis (4) of its eccentric (5) is perpendicular to the upper piece (16) of this stack.

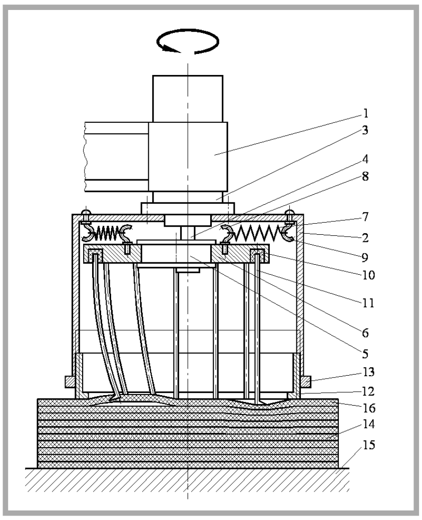

Figure 4. *Start of pattern gripping operation.*

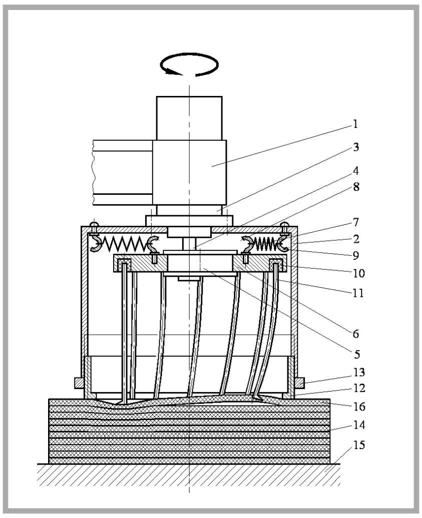

Figure 5. *End of gripping a pattern from the stack.*

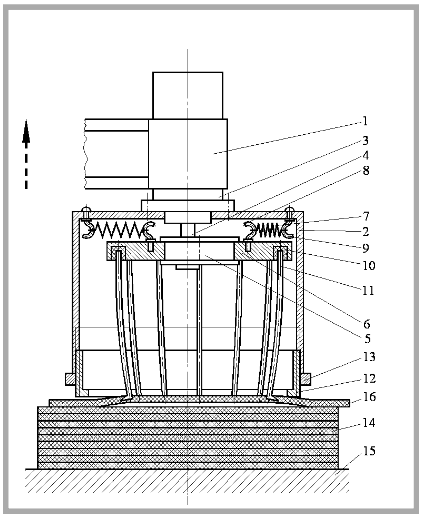

Figure 6. *Separation of a pattern out of the stack.*

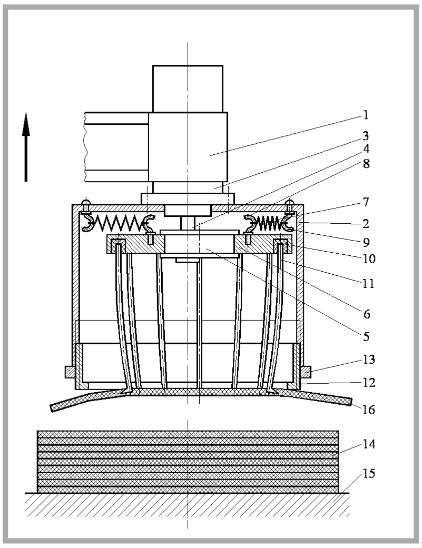

Figure 7. *Conveying of a pattern.*

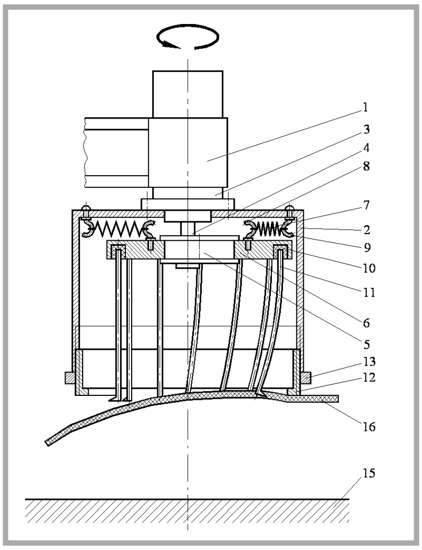

Figure 8. *Start of pattern release.*

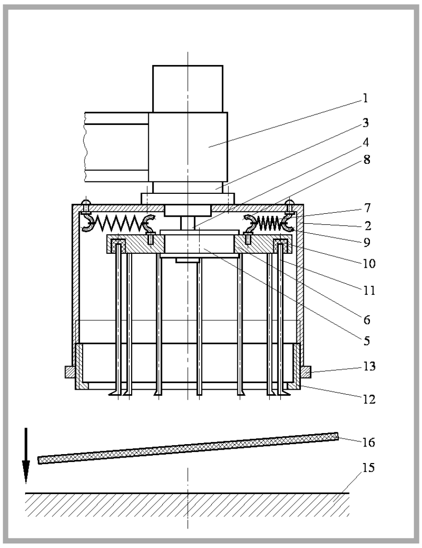

Figure 9. *Release of a pattern.*

The gripper is lowered on the stack of cut textile pieces in order to grip a textile piece (Figure 3). The limiter (12) rests against the upper piece (16) of the stack, and the gripping elements (11) pierce the upper piece, partly deforming the other textile pieces lying under it in the stack (14). The depth of piercing into a textile piece by a gripping element is adjusted at the beginning of work by turning the limiter (12) in the housing (2), and considering the thickness of the piece.

The drive (3) is engaged after the gripper is lowered. The eccentric (5) starts to rotate. The holder (6) moves together with the eccentric (5) in one plane, swinging around the centre of its curvature. The upper ends of the gripping elements (11) move in close trajectories together with the holder (6), while the lower ends either pierce the upper piece (16) of the stack or slip on its surface. The piercing depth of the gripping elements depends on the length of the bent part of their lower ends and the angle they are bent at. The gripping elements, with their lower ends bent and sharpened, pierce into the upper piece of the stack and become bent, while the gripping elements (whose lower ends slide over the surface of the piece) remain straight or bend to the opposite side, lifting their sharp tips from the textile piece when the eccentric rotates (Figure 4).

Usually all the lower ends of the gripping elements (11) pierce the upper textile piece (16) of the stack when the eccentric (5) revolves once (Figure 5). The textile piece is stretched between gripping elements (11) piercing it, as well as between the elements and limiter (12), due to the deformation of the elastic gripping elements. In addition, the textile piece held under the gripper is slightly lifted and partly separated from the rest of textile pieces in the stack (14), because the lower ends of the gripping elements move in a horizontal direction, rise slightly, and deform in the plane of their bending.

The upper ends of the gripping elements are fastened in the sensors (10) in order to increase the reliability of gripping. The sensors enable us to determine whether the upper textile piece of the stack is gripped by all the gripping elements without lifting the gripper from the stack. The gripper's working parameters are adjusted with reference to the analysis of the sensors' (10) signals. The textile piece can be gripped again by increasing the gripper's pressure force to the stack, and turning the eccentric (5) once more. The gripping elements already piercing the textile piece do not release it, and the free gripping elements move over the surface.

The gripper is lifted when the textile piece (16) is gripped. After lifting the gripper, the limiter (12) does not press the picked up textile piece to the stack. The piece moves aside a little, occupying a new equilibrium position due to the deformed gripping elements (11) (Figure 6). The textile piece which has been picked up will separate from the stack more easily if the gripper is lifted with the engaged drive. The textile piece which has been picked up starts moving in a plane parallel to the remaining textile pieces in the stack, thus causing the adhesion forces to decrease.

The textile piece which has been picked up is suspended between the deformed gripping elements (11) when the gripper rises up. This suspended piece is conveyed to the spot where it must be put (Figure 7).

The gripper is stopped over the piece drop spot, and the drive of the eccentric (5) is engaged. The eccentric is revolved at a higher speed, and moves the holder (6) and gripping elements (11) more intensively. The piece picked up (16) deforms the gripping elements (11), and their catchers leave the textile piece due to inertia and centrifugal forces (Figure 8). The released piece falls down on the indexed spot (Figure 9), while the manipulator sends the gripper back to the initial position. The cycle is repeated.

Control of the pick-up device

When performing the above-mentioned operations, it is important that the control system can determine the position and the state of the flat flexible textile pieces being manipulated, and that the robot actions can be corrected according to the obtained information. The industrial robot can be easily adapted to the technological process and environmental changes if such information is obtained.

At the interaction process of the device with the piece being manipulated, this piece exerts an influence on its working elements in one way or another. Inertia forces also arise when the piece is moving or positioning. It is convenient to use them to obtain information about the operation, as these forces are present in all stages of the device's operation cycle. The textile piece being handled through the elements of the device influences its sensitive structural elements (the sensors), and thus an information about the position of the piece can be obtained according to these signals. The most convenient way to obtain information about the technological operation or manipulation of an object is from a part of the device which is in contact with the piece treated (structural elements of the device, or technological tools). Sensitive transducers are fixed in the device parts in order to obtain this information [15, 16]. The information about the technological process is obtained from the following sensors: the position of the flat flexible piece on the supply table, the pressing force of the pick-up device on the stack of flat flexible pieces, the deformation force of the catchers, the rotation parameters of the grippers' cam, and the handling of the cut textile piece for transferral to the following technological operation.

The process of manipulating the textile piece is checked in the gripper as presented. The gripping elements are mounted in a holder by an intermediary element which is sensitive to the working factors of the gripper. The industrial robot presses a gripper on to the textile piece with a certain force, and the piece responds to its catchers during the working process. The interaction of the gripper, and even the gripping elements when holding a textile piece they have picked up, give information about the change to the stack's parameters, the conditions of gripping, etc. The textile piece picked up deforms the intermediary gripper's construction elements (sensors) by the gripping elements. Their signals make available information about the gripping conditions of each gripping element. Grippers which are sensitive to the changes of working conditions are called adaptive, and belong to the second generation of grippers [19].

The device is controlled by a microprocessor controller. The signals of all the device sensors are processed by a microprocessor. This information in the controller's memory, according to the input signal and the resulting value of the intermediate computation, forms the output signals using the application program controlled by the operation system. After further transformation and processing, these signals take a form (if necessary) suitable for input to actuators, i.e. the driver of the gripper cam and the drivers of the robot. At present, programmed logical controllers are being used more and more widely, because the realisation of programmed algorithms is cheaper and more flexible than hardware ones.

The flowchart of the control of the device supplying the cut textile pieces is shown in Figure 10.

At the beginning of the device's operation (block 1), all the device elements and systems are checked (block 2) and initial conditions (block 3) are determined. They are as follows: maximum allowable pressing force of the pick-up device onto the stack of cut textile pieces Q_{adm}, its initial magnitude Q, its change ΔQ, the number of pieces already manipulated N, the number of pieces to be manipulated N_d , the angular frequency of rotation of the gripper cam while gripping the piece ω_{2s} , the angular frequency of rotation of the gripper cam while releasing the piece ω_{2n} , and its change $\Delta\omega_{2n}$ (block 3). The operation cycle starts after determining the necessary conditions and technological parameters (block 4). The parameters N, Q and ω_{2n} are reset at the beginning of the operation cycle of separating the piece after the device starts (block 5), if they had been changed before. The device is lowered onto the stack for entering the gripping elements in the contact with the upper textile piece. When the pick-up device is lowered onto the stack of cut textile pieces (block 6), the magnitude of the pick-up device's pressing force on the stack Q and the angular frequency of rotation of the grippers cam during gripping of the piece ω_{2s} (block 7) are determined; also it is checked whether its pressing force on the stack of cut textile pieces does not exceed its admissible value Q_{adm} (block 8). The drive of the gripper's cam is switched on to start the gripping process (block 9). While gripping the upper piece of the stack, the control of the quality and the conditions of gripping (block 10) are performed. The pick-up device is lifted from the stack after the end of the gripping process (block 11). If the conditions of gripping are satisfied, and the piece gripping has been checked (blocks 12 and 27), the piece gripped is transported to the positioning zone (block 13) and positioned there (block 14). Checking and defining the parameters of the release of the positioned piece is performed after

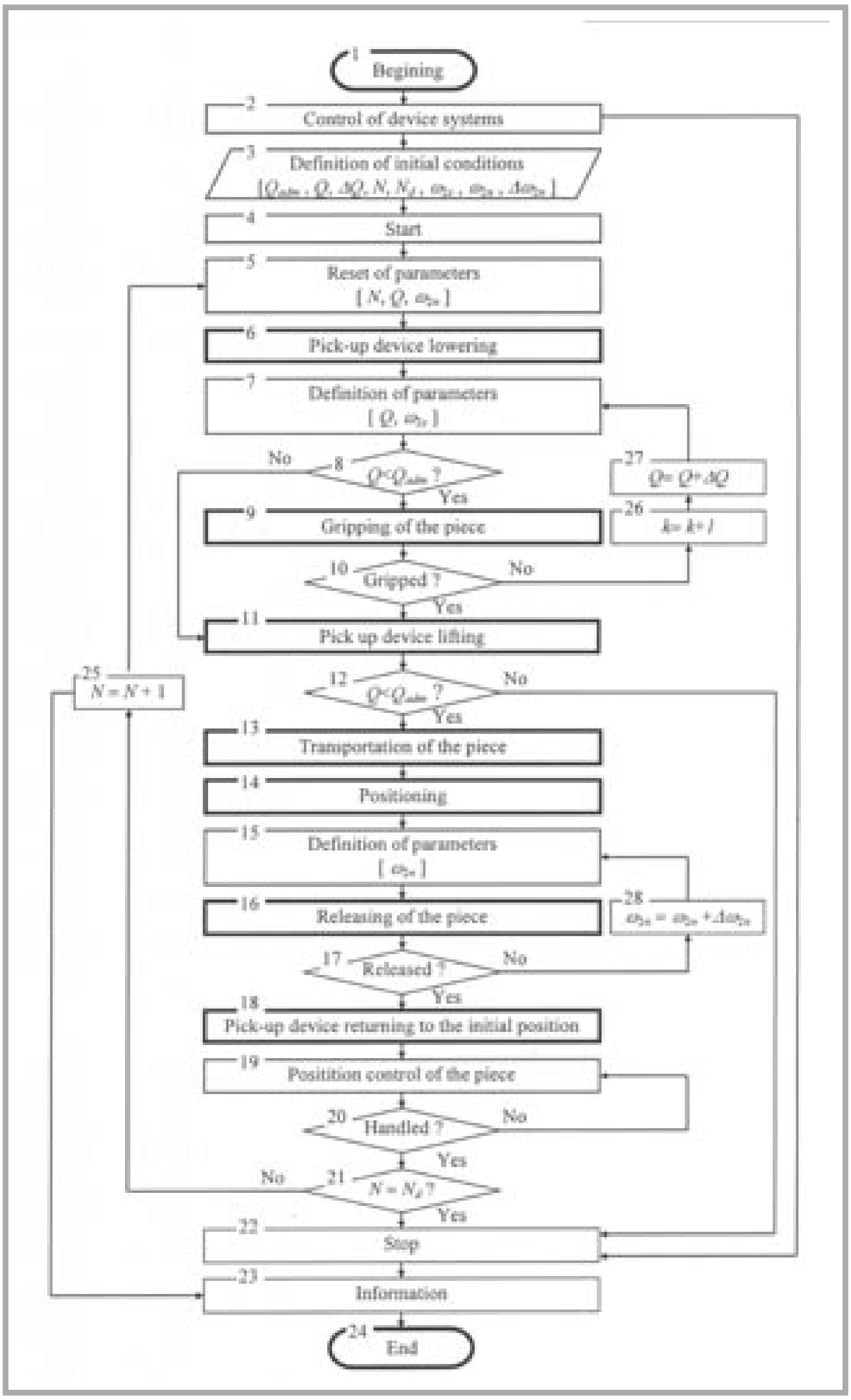

Figure 10. *Flowchart of the cut textile pieces pick-up device control.*

its positioning (block 15). The drive of the gripper's cam is switched on to start the releasing process (block 16). The control of the conditions of the release of this piece while releasing the gripped and transported piece is then performed (block 17). After release, the piece falls onto the horizontal surface of the table with a presence sensor. The pick-up device returns to its initial position over the stack of cut textile pieces (block 18). The piece position check is performed for the formation of the control signal for the following operations (block 19). The piece remains in such a position until it has been handled for transportation to the following technological operation (block 20). The number of transferred pieces is checked after the separated pieces (block 21) have been transferred and the device is stopped (block 22), when it is confirmed that the last piece has now been transferred. The information about this is indicated (block 23), and the pick-up device is prepared for the next action (block 24).

The current information about the number of the transferred/handled cut textile pieces is transmitted (block 21) for the on-line correction of the pick-up device's action parameters (blocks 25 and 5), and the information about the current transferred/handled cut textile pieces is indicated on-line (block 23) also.

Blocks 1-24 correspond to the process of separating one cut textile piece from the stack in this flowchart when it is separated from the stack on the first attempt.

The gripping process may be repeated for an indeterminated number attempts if the piece is not gripped on the first attempt. Each successive gripping attempt is preceded with the augmented pressing force of the pick-up device to the stack of cut textile pieces (block 26). This process is repeated until the textile piece is gripped (block 9), or the number of gripping attempts *k* is bigger than a fixed number, or until the maximum admissible pressing force Q_{adm} on to the stack is exceeded (blocks 8). After that, the gripper is lifted up if the piece has been picked up or the number of attempts or the force Q_{adm} has been exceeded (block 12), next the gripper either continues its work or is stopped, and the reason of stopping is signalled (blocks 17 and 18).

The release of the manipulated and positioned piece is resumed with an increased magnitude of the angular frequency of rotation of the grippers' cam ω_{2n} until this piece falls onto the horizontal surface of the table (block 28). If the piece has not been released during the first attempt (blocks 16 and 17), the angular frequency of rotation of the grippers' cam during the release of the piece ω_{2n} is increased by the change $\Delta\omega_{2n}$ (block 28); the parameters of the release process are adjusted (block 15), a second attempt is made to release it (block 16), and then the release of the piece is checked (block 17). This process is repeated as long as the piece is released. The gripper work is continued after the piece is released (block 18).

The device is stopped, and the information about this is given according to the signal (block 2) of whether the stack was installed placed on the table, or according to the signal (blocks 8 and 12) whether the magnitude of the pressing force of the pick-up device onto the stack of cut pieces exceeds the maximum allowable pressing force of the pick-up device onto the stack of cut textile pieces Q_{adm} (block 27), or whether the piece is not gripped after several attempts (block 26).

The number of parts already transported N is corrected if not all the pieces of the stack have been separated (parameter N_d) (block 21) and written to the piece counter (block 25). The following operation parameters are reset (block 5), if they have been changed earlier (blocks 21, 25, 27,28): the number of parts already transported N, the pressing force Q of the pick-up device on the stack, and the angular frequency of rotation of the grippers' cam while releasing the piece ω_{2n}. The operation cycle of the device is continued.

Conclusions

- Separating the flat flexible piece from the stack along its upper surface reduces the working strokes and increases the reliability of the device's action .
- By applying the device presented, it is possible to control the technological process in a more flexible way, or correct it rapidly if errors appear.
- The device is more complicated and expensive in comparison with its analogues. Nevertheless, its functioning does not need additional objects for manipulation, storage and orientation devices or any other special equipment.
- Such devices are easily adjusted to the manipulation objects and their variable assortment. They are convenient for usage in frequently readjusted flexible production lines. The main advantage of this device is its high reliability of operation.

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