# Comparative analysis of the manual and robotic upholstery frame assembly processes. Study based on many years of research

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**Abstract.** A robotization of assembly is the real implementation of Industry 4.0 in the furniture industry. The robotization objective is to obtain favorable values of production process parameters (performance, productivity, quality) and to improve human wellbeing at work. Our aim was to present and compare the quality parameters of a selected furniture production process, performed in a very long series, containing more than 30 thousand products. The analysis included the results of the long-term measurements of the quality level of upholstery frames produced by the modified and improved, on the basis of operational conclusions, robotized line for the serial production of upholstery frames and by the simultaneously used nonrobotic line for assembly of frames of the same construction. The results obtained show that robotized assembly leads to a much lower percentage of defective products than in the case of the nonrobotic technology, the causes and types of defects in the products are also different, and it is easier to prevent these defects and remove them. The cognitive findings identified problems and challenges, not found in traditional technologies, caused by the using of manufacturing robots in furniture production.

## 1 Introduction

Robotization in industry is the replacement of human labor with the robotic systems, i.e., cyber-physical devices controlled by computer algorithms and numerous sensors. This trend is one of the expressions of the so-called Industry 4.0 in the furniture industry [1]–[3]. Robots substitute humans in technological processes with repetitive operations, without variation. The advantages of robotic production lines include better process parameters and improved working conditions, especially moving operators away from activities that are dangerous (e.g., they are associated with excessive body overload, noise, or risk of accidents) [4], [5]. Robotization, apart from the obvious advantages, also brings new challenges, forces the use of new methodologies to solve line balancing problems [6], or can increase the consumption

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of electricity [7]. Robotization is usually perceived through the prism of performance and productivity, but it also has a great impact on the level of product quality [8]. It is characterized by the elimination of many problems with the repeatability of product quality in the series, but on the other hand, there are completely new challenges in the aspect of quality assurance, not present in technological processes performed by humans. The aim of this paper was the numerical presentation and comparison of quality parameters of an upholstery frame assembly process performed in a very long production series, consisting of over 30 thousand products, and a comparative analysis of the quality results of manual assembly with robotized assembly.

## 2 Materials and methods

### 2.1 Materials

The subject of the described qualitative study concerned upholstery frames used in furniture for seating or laying. The upholstery frame is rectangular, made of pine rails, has corrugated springs arranged in series, and the corner junctions are twin bridle joints, glued and additionally stapled. The ends of the springs are placed in the spring holders. A metal strut screwed with wood screws is an additional reinforcing element, providing strength and rigidity to the frame. The frame being tested is presented in Figure 1.

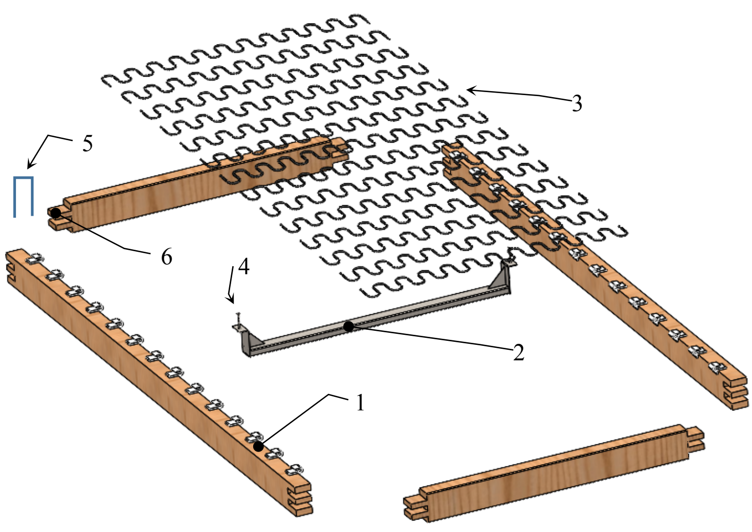


**Fig. 1.** Upholstery frame construction (description in text).

The components for the robotic assembly are: (1) four pine rails (two of them with plastic spring holders already installed with staples), (2) steel strut, (3) steel corrugated springs, (4) screws for fixing the strut, (5) staples for corner joints (4 pcs for each joint), (6) PVAc glue for corner joints. The assembly process consists of: (a) positioning the rails, (b) making the corner joints (covering with glue, pressing, stapling), (c) assembling the strut with screws, (d) attaching the springs.

The subjects of the described analyses were frames of the same construction, appearing in three dimension variants (spring lengths 520, 560 and 660 mm).

## 2.2 Methods

The qualitative study consisting in the assessment of the quality level was carried out on a batch of upholstery frames produced with the technology consisting in:

- manual assembly line,
- robotized assembly line.

The manual assembly is carried out at a work centre, whose main element is the assembly table (Fig. 2). The assembly table has the form of a frame construction, with a built-in mechanism that supports spring tension when placing a set of springs in the holders (Fig. 3).

a b

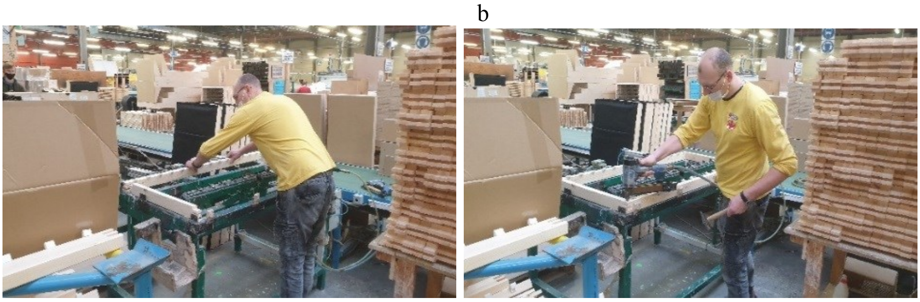

**Fig. 2.** Manual assembly of the upholstery frame: a – arrangement of components, b – assembly of the frame.

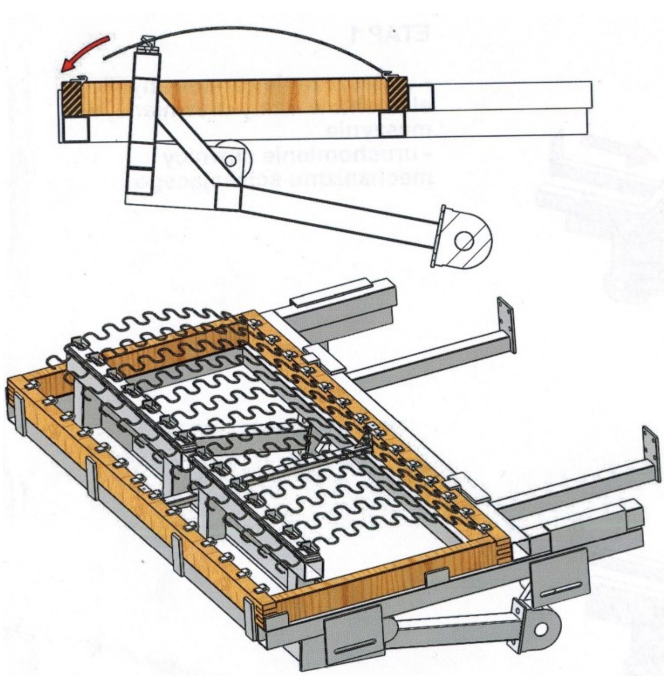

**Fig. 3.** Operation principle of the Euroline spring assembly jig.

Manual assembly of the frame consists in:

- taking four rails (1) (front and rear with spring holders and two side rails),
- putting glue to make four corner bridle joints (6),

- putting the rails to the rails junction jig in the assembly table,
- mechanical compression of the rails,
- attaching both sides of each frame corner using staples (5),
- fitting the bracing strut (2) and screwing it down with two screws (4),
- attaching springs (3) on one of the rails (in holders),
- mechanically fixing all the springs in spring holders in the second rail, using the spring assembly jig (Fig. 3),
- spring alignment improvement in order to improve their fitting,
- putting the ready frame on the pallet (storing position).

Manual assembly usually involves three workers. It is possible to involve two or even one worker, but this affects the assembly performance.

The robotic assembly of the frame is performed using a robotic and automated production line (Fig. 4) consisting of: rail junction and strut fastening section, internal transport section, spring insertion section, palletizing section and autonomous receiving transport section.

a b

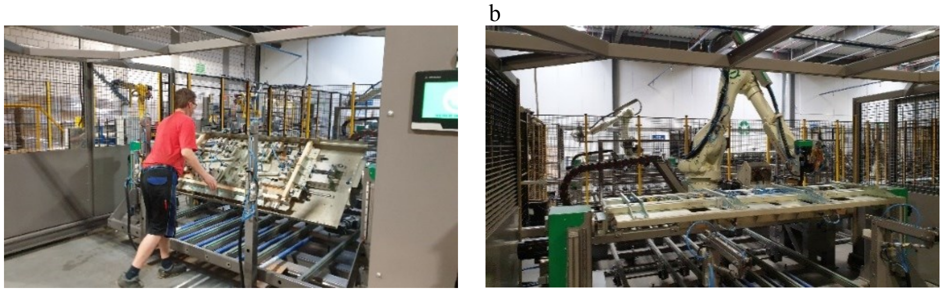

**Fig. 4.** Robotic assembly of the upholstery frame: a – operator unfolding the rails, b – robot assembling the frame.

The robotic assembly consists in:

- placing four rails and a bracing strut by the operator in the rails junction jig,
- automatic glue application on the ends of rails,
- automatic squeezing the rails and creating corner joints,
- stapling with a robot of each corner joint – the first side, two staples per corner,
- automatic rotation of the rails junction jig and stapling the corners with the robot on the other side of the frame,
- screwing the strut by a robot,
- automatic release of the frame from the rails junction jig to horizontal conveyors and its transport to the spring insertion section,
- inserting all springs by a robot,
- automatic release of the frame and transport by a roller conveyor to the palletizing system, where the frames are placed on pallets with the use of a robot, different depending on the type of product – segregation by type,
- automatic transport of frames on a pallet to the automatic film wrapping section to secure the load for transport to the warehouse or to the production,
- automatic collection and release of finished products and autonomous transport to the final destination.

During these automatic operations, the operator supplies the second assembly rails junction jig with rails and a bracing strut. The supply operator performs alternating work with the stitching and screwing robot at two assembly rails junction jig.

The robotized line can be operated in two variants, in a one-way variant or in a double variant, in which the flow of material on a certain section is forked into two paths. In the first variant, two operators are required and in the second variant, three operators are required. The operators' role is to supply the line with parts for assembly and to supervise the robotic assembly process. The quality measurement consisted of:

- taking a random batch of 1000 frames from a manual assembly series of 10 000 pieces and determining the percentage of defective products (with identification of these defects),
- supervising the quality of all robotically assembled frames produced in the two selected months (September and December 2020); in these months, respectively: 2000 and 1200 frames, and between the measurements many changes were made to the process parameters resulting from the conclusions of launching the robotic line).

# 3 Results

Based on manual assembly analysis, ca. 25% of the frames were found to have minor or major assembly defects. All of these defects were repairable. The results from the manual assembly technology are shown in Table 1, which includes a categorization of the identified defects.

**Table 1.** Categories and percentages of manual assembly defects

| **Category** | **Defects** |
|---|---|
| Staple protruding (sharp, missing) | 31,93% |
| Element mismatch | 26,89% |
| Element not stapled | 13,57% |
| Spring assembly defect | 8,92% |
| Element missing | 5,43% |
| Unscrewed screw | 5,24% |
| Assembly place not blocked | 3,62% |
| Glue leakage | 3,17% |
| Missing glue | 1,16% |
| T-nut wrongly inserted | 0,06% |
| **Total** | **100,00%** |

In the analysis of defects concerning frames manufactured in the manual assembly process, 10 categories of defects were distinguished. Two categories of defects were the most frequent: a badly installed staple (not fully nailed in or nailed at the wrong angle or in the wrong place in such a way that the staple blade protruded from the frame). The second category of defects was poor fit of the elements.

On the basis of robotic assembly analysis, less than 2% of the frames were found to have assembly defects. The results of monitoring the percentage of defective frames for the two analyzed months are presented in Table 2.

**Table 2.** Most common defects in robotic assembly

| **Month of testing** | **Springs not assembled 520* (%)** | **Springs not correctly fitted 520* (%)** | **Springs not correctly fitted 560* (%)** | **Springs not assembled 660* (%)** | **Springs not correctly fitted 660* (%)** | **Staples missing (%)** | **Misalignment on pivots (%)** | **Pivots not tightened (%)** | **Broken frames (%)** |
|---|---|---|---|---|---|---|---|---|---|
| September | 0-0.16 | 0-0.27 | 0-0.28 | 0-018 | 0-0.19 | 0-0.08 | 0-0.2 | 0-0.34 | 0-0.92 |
| December | 0-0.3 | 0-0.12 | 0.012 | – | – | 0-0.2 | – | – | 0-0.28 |

* – spring length in mm

A comparison of the data in Table 2 shows that the percentage of defects for each category in the robotic process is less than 2%.

## 4 Analysis of results and discussion

The main technological problem in the frame assembly is the mounting of springs. The observations indicate that this operation has the biggest influence on the frame assembly quality. The tension force of one spring can be even approx. 350 N. Therefore, sometimes hand tools or machines are used to assist this process. Examples include a hand tool called the Upholstery Spring Tip Bender [9] or a slightly more advanced device called the Spring Strether described in the US patent from 1992 [10]. The concept of a mechanical device for uncoupling corrugated springs is described in the US patent from 1995 [11]. An example of an advanced machine tool for mechanization of spring assembly can be the NS1 machine manufactured by Rexel, developed in 2014 [12]. In the analyzed case, the manual assembly uses an original Euroline spring assembly jig with a crank mechanism to support the process.

Both analyzed technologies definitely differ in the percentage of assembly defects: the manual process – percentage of defects 25%, the robotic process – percentage of defects does not exceed 2%. Human who has made an error may repeat the action and remove the error [13] however, he usually does not because he is more concerned with process efficiency than with quality. In the manual assembly errors are concentrated in activities that require precision (staple insertion and proper positioning of elements), while in the robotic assembly they concern spring insertion and damaging wooden rails by the robot. For these two reasons manual assembly defects are completely different from robotic assembly defects. In general, it can be stated that defects in robotic assembly are much easier to detect, and the products are easier to fix than in manual assembly (the main category of defects in robotic assembly are easy to repair spring montage errors).

Manual assembly differs from robotic assembly in performance and productivity. The robotic process involves up to three workers. While the manual process requires three times as many people to complete the same number of frames in the same amount of time, including the associated process workers. A comparative summary of the productivity of these two processes is shown in Table 3.

**Table 3.** Performance comparison between manual and robotic assembly

| Parameter | Robotic line | Manual production |
|---|---|---|
| Number of workers | 2 (1 line) or<br>3 (2 lines) | 3 |
| Performance | 70-75 pcs/h (500-550 pcs/shift)<br>140-150 pcs/h (1000-1100 pcs/shift) | 26-27 pcs/h (195-202 pcs/shift)<br>78-81 pcs/h (585-605 pcs/shift) |

Table 3 shows that with the same number of people (three operators) in the robotic process it is possible to achieve almost twice the productivity of manual production. Therefore it is possible to shorten the working time of the line for a given type of product to one shift covering the demand of two production shifts. As a result of the available saved time, it is possible to use it after some modifications and adaptations to produce another product. As a consequence, the operators who can be employed in other processes are "regained".

A labor-intensive process is the assembly of spring holders on the rails. The automation of the assembly of the spring holders on the rails will be the next stage of modernization to increase the degree of robotization of the production process. Table 4 shows a comparison of the two ways to perform this activity.

**Table 4.** Spring holder insertion on the rails

| Parameter | Robotic line – new machines with feeding robots | Old machines (currently) |
|---|---|---|
| Number of workers | 0.2 – 0.3 | 2 |
| Performance | 435 pcs/h (3262 pcs/shift)<br>after improvements 575 pcs/h 4312 pcs/shift) | 206 pcs/h (1545 pcs/shift) |

As can be concluded from Table 4, two new machines with robotic feeders replace the five old machines and 4-5 operators per shift (8-10 operators for 2 shifts).

The most difficult challenge in selecting the process parameters of a robotic assembly line is the problem of synchronizing its individual components (robotic assembly line balancing problem – RALBP [14]) and making them as insensitive to process disturbances as possible.

## 5 Summary, main conclusions and observations

The robotic process is characterized by favorable parameters of quality, performance and productivity, and offers better working conditions for operators. The initial cost of building and launching a robotic line is quite high, and the individual components must be supervised and maintained by qualified personnel. There is also a greater risk of failure. In the case of complete reliance on robotic assembly, production can be interrupted for several hours or even days. Robots are characterized by a lack of flexibility: although a robot can perform the same tasks repeatedly, but if changes are required, it must be reconfigured, and this requires additional time and money. It is much less flexible and susceptible to changes in dimensions and other parameters of the input parts (e.g., variation in the dimensions of spring holders beyond a certain tolerance level is unacceptable in a robotic process, and irrelevant in manual assembly). The key differences of the two analyzed processes are compared in Table 5.

**Table 5.** Comparison of manual and robotic assembly

| Parameter | Manual assembly | Robotic assembly |
|---|---|---|
| Performance | low | high |
| Productivity | low | high |
| Susceptibility to changes in product parameters (eg. dimensions) | high | low |
| Quality level of products | moderate | high |
| Resources and time required to implement the process | moderate | high |
| Operators' workload | high | low |

Based on quality measurements and observations, it can be concluded that:

1. The cause of more than 95% of defects in the nonrobotic production of upholstery frames with corrugated springs are human errors, the causes of which lie in technical, training, documentation and technological aspects.
2. The manual assembly defects are the result of badly performed precise operations (staple insertion and proper element positioning), while in the robotized assembly they concern force issues (insertion of springs and damaging of wooden frames), and the defects are the result of variation in the properties of assembled elements (e.g. inaccuracy of spring holders, wrongly placed spring holder, inaccuracy of processing of wooden frame pivots).
3. The causes of robotic assembly errors are easier to identify and more amenable to corrective action. In the analyzed case it was found that the biggest source of defects was the dispersion of constructional properties in the assembled elements.

An important effect of robotic assembly is the high quality and repeatability of manufactured products. Standardization of all technological operations is required and implemented in this process. There is also a noticeable professional development of employees who increase their knowledge of their work and responsibilities. These aspects can be applied not only to furniture production. They are universal and reflected in other branches of industry.

From the production management point of view, improved quality and productivity is easier to implement, as a result of high technical advancement of the robotized line and the monitoring and support systems used, but also as a result of possibility of current process control and its manageability. The availability of data allows for a thorough analysis of the process to modify and improve it. The difference between a robot and a human is significant. The robot can operate almost 24 hours a day, always works with the same performance, is repeatable and predictable – it does not take breaks, does not simulate problems, will always perform the task in the required and assumed quantity without disturbing the production rhythm. With high accuracy it is possible to determine the time of order execution (ease of planning). The robot is always available (regular service required), it requires an increase in operators' qualifications, which in turn translates into their development, high awareness, technical knowledge and competitiveness in the labor market.

Taking into account the features of robotic processes and their interrelationships, it is easier to achieve high quality of manufactured products, which in turn results in competitiveness and development of not only the company implementing robotic processes but also of its cooperating partners.

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