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Optimization of assembly devices of automated workplaces using the TRIZ methodology

Karol Vanko[1], Lukáš Pompáš[1*], Rudolf Madaj[1], Martin Vicen[2], Jozef Šutka[3]

[1] Faculty of Mechanical Engineering, Department of Design and Mechanical Elements, University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovak republic; vanko.karol@gmail.com (KV); lukas.pompas@fstroj.uniza.sk (LP); rudolf.madaj@fstroj.uniza.sk (RM)
[2] Faculty of Mechanical Engineering, Department of Materials Engineering, University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovak republic; martin.vicen@fstroj.uniza.sk
[3] Faculty of Mechanical Engineering, Department of Technological Engineering, University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovak republic; jozef.sutka@fstroj.uniza.sk
*Correspondence: lukas.pompas@fstroj.uniza.sk

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Abstract
The presented article familiarizes the reader with optimizing the workplaces of ultrasonic welding machines. The essential part of the article deals with prototypes, the construction of which does not meet the requirements for production, economy, and functionality. The experimental analysis runs pointed out shortcomings and inaccuracies. The developer's team used one of the well-known optimization and design methods to solve this issue. It is the TRIZ method (Creating and solving creative assignments). The mentioned method combines two powerful tools into one whole. Specifically, it is the Function and Cost Analysis (FNA) and the algorithm for solving creative assignments (ARIZ). The manuscript describes the use of the method for a more straightforward solution to problematic parts of the structure. The result of the optimization process is a new, improved structure whose properties were confirmed in terms of stiffness by simulation in the ANSYS Workbench program. The applications of optimized parts will also be used in other similar devices. The research will follow up with the design of a new series of ultrasonic welding machines in the future.

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1. Introduction

This manuscript's main topic is improving the malfunction of special equipment for ultrasonic welding. Every machine and device is a technical system that is supposed to fulfill its function in the first place. Secondly, it should be manufacturable under available conditions from available materials. Existing prototypes during experimental testing run point to design flaws. The welding part using ultrasonic welding (fixing welding heads) became problematic.

An ultrasonic welding machine has four main components - source, converter, amplifier, and sonotrode. The source produces high-frequency electricity (20-40 kHz) from low-frequency (50-60 Hz). This electricity is then converted into ultrasound using a transducer. Subsequently, it is necessary to amplify the vibrations of high-frequency sound utilizing an amplifier. The sonotrode then directs the ultrasonic waves to the bonded (joined) materials. Mechanical high-frequency waves are crucial in ultrasonic welding to achieve the required result. Thanks to the heat generated during molecular friction, joining materials is easier (NOTUS, 2023; Wang et al., 2007; Fang et al., 2018)

In ultrasonic welding, two pieces of material are joined together through high-frequency acoustic vibrations (Troughton, 2008; Bhudolia, et al., 2020). Ultrasonic waves are waves at high frequencies that lie above the limit of hearing of the human ear (the limit of hearing of waves 20kHz). Acoustic energy is converted into heat energy by friction. It is possible to create a connection almost immediately. A high advantage of this method is the long service life of welding tools. Currently, it is known for use in welding plastics and metals (EMERSON, 2023; Gallego-Juarez et al., 2014; Gupta et al., 2021; Sahoo et al., 2020; Zhang et al., 2022).

The use of ultrasonic welding is different, while it is most common where you work with plastics (thermoplastics) or metals (electrical components). Typical examples of use are, for example, the automotive, aviation, electro-technical, and packaging industries. The method is used by welding new materials such as composites. The quality of the weld is influenced by the amplitude of the deflection of the welding tip, the magnitude of the pressure force, the frequency, and the welding time (Mongan et al., 2022). The position of the fixed part, the bonded element (the size of the contact area), and the joined parts' natural frequency impact the welded joint's quality. The design and shape of the sonotrode itself have a significant impact the quality and efficiency of ultrasonic welding (Shu, 2013; Kuratani et al., 2019).

The search for innovations is a movement of thinking "from what already exists to what is coming" (Orloff, 2006). By introducing any invention, we can improve or even "worsen" the existing properties of the equipment. To solve problems in existing structures, it is often necessary to investigate the essence of the solution and undergo the optimization process. (Tomašiková et al., 2017; Tropp et al., 2017; Tropp et al., 2018). The "Theory of Inventive Problem Solving" technique is among the systematic methods of creating innovations, marked by the abbreviation too TRIZ.

The essence of the methodology by Genrich S. Altschuller is the generalization of successful procedures from the study of patents, which primarily solved problems of a technical nature. The method shows the performance of an essential analysis of technical systems in their physical essence. Even if they have a patent nature, the most robust solutions are created by solving material contradictions (Altschuller 1999; Katolický et al., 2014; Palčák, 2016). The methodology provides a powerful tool for design innovations (Bultey et al., 2015; Kaplan, 1996). The main components of the method are the preparatory stage, the information stage, Functional Cost Analysis (FNA), the algorithm for solving innovative tasks (ARIZ), the verification stage, and the implementation stage. (IPASlovakia, 2017).

The first parts of the methodology are the preparatory and informational stages following the FNA, which analyzes the technical system and reveals the so-called sources of possible improvement. The main parts of FNA are analysis of components and structures, analysis of functions, model of operations, and development/development of technical systems and processes. Through generalization, we can formulate the essence of the problem and find the origin of the problem. (Skařupa, 2007; Terninko et al., 1998; Chechurin et al., 2016).

Analytical inputs form the basis for the ARIZ algorithm, which resolves the resulting contradictions. By formulating the first cause and the technical rejection, we should also be able to define the physical paradox. If the formulation of the physical disclaimer (separation procedures) fails, the task can be solved at the level of technical rejection using heuristic procedures. The best solutions are created by solving physical contradictions, whereby fulfilling the requirement, we cause effect A (desirable), but we also cause effect B (undesirable) (Akay et al., 2008; Hipple, 2005; Rantanen et al., 2007).

An example of the successful use of the TRIZ methodology can be e. g. case study of an automation station for sheet metal allocation. Due to the high requirements for security, robustness, maintenance, and costs, a systematic approach was necessary to formulate a successful solution concept (Gronauer et al., 2016). Another example could be the application of the system operator (nine boxes/multiscreen), which is often associated with the TRIZ methodology and the analytical part (FNA). Using a method to analyze an undesirable situation can be done from different points of view. Specifically, the case study applied TRIZ to compostable packaging bending tests (Fiorineschi et al., 2021). The use of the methodology is different.

The presented article initially focuses on the constructed device, which is in the prototype stage. The design team used the TRIZ methodology to facilitate the equipment optimization process. The result of the work should be a device with a more suitable construction and better fulfills its function without other adverse phenomena.

1.1. The current state of the device

The article focuses on the optimization process of de-vices for ultrasonic welding of plastic parts. In the current state, the constructed devices are in the prototype phase based on customer requirements. The first device (Figure 1) with the numerical designation 106_05_01 is called a “small ultrasonic welder”. The second device (Figure 2) with 106_05_02 is called a “big ultrasonic welder”. The main task of the devices is to create inseparable connections between several plastic parts as accurately as possible. In the equipment frames, there are sliding tables with beds for inserting parts. In the other parts of the frame, the welding heads and elements for their displacement, position control, cooling and control of the welded parts are stored. Deficiencies in constructions became apparent during test runs. The problem areas prevent the performance of the main functions of the devices. (Čačo et al., 2017a, Čačo et al., 2017b).

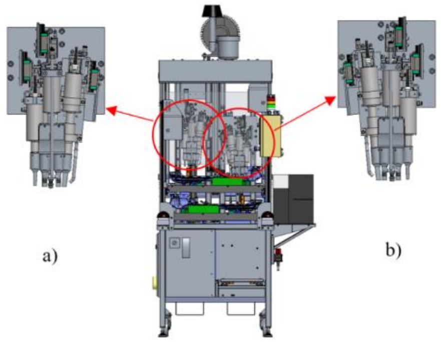

Fig. 1. Assemblies of welding nodes of machine 106_05_01
a) Right part, b) Left part

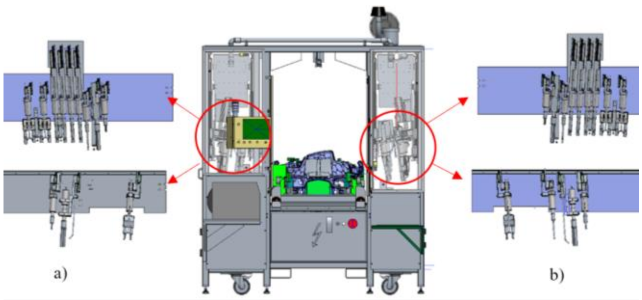

Fig. 2. Assemblies of welding nodes of machine 106_05_02
a) Right part, b) Left part

The design team needs to optimize the design and improve the device's properties before producing additional devices (new series). The prototype devices from Figure 1 and Figure 2 used welding assemblies for the left and right parts. The types of fasteners, due to their construction (welded assemblies, linear guideways, pneumatic cylinders), do not necessarily fulfil their function. Fixing the welding heads in the device is complicated (Figure 3 and Figure 4). Many components of different shapes and sizes are fixing the welding head, but they do not fulfil their function correctly. Unreasonable mounting load causes deflection. The sonotrodes are attached to the device using single-point and two-point fixings. Individual elements of construction nodes may differ in shape and size, but their functions are the same. The structural assembly of the head consists of a linear guideway, a pneumatic cylinder, supporting elements (mounting structure), and a sonotrode (welding assembly).

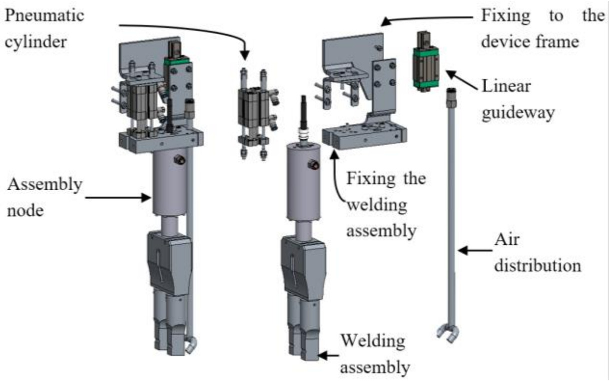

Fig. 3. Technical system of the assembly node for one-point fixing

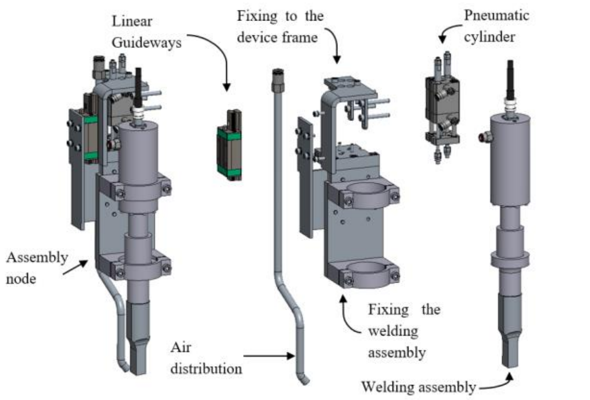

Fig. 4. Technical system of the assembly node for two-point fixing

From the analysis of the current state of the equipment, in constructing both types of ultrasonic workstations, a kind of linear guideway, one type of pneumatic cylinder, nine types of welded assemblies and fifty-two different manufactured parts are used in the given assembly nodes.

2. Optimization process with TRIZ methodology

For a better understanding of the technical system, it is advisable to create complete model functions. This model will allow us to understand the relationship between the technical elements and between the technological operations of the system concerning the distinction of their hierarchy (Gronauer et al., 2016; Terninko et al., 1998).

2.1. FNA Analysis

Determining the importance and hierarchy between individual parts of the system is relevant. By proposing a hierarchical structure, it is possible to clarify individual relationships between system members and determine functions. The primary function (M) can be understood as the function bearer's main purpose (object, element). With essential function (B), we can talk about the basic function (object, element). Help function (H) helps to carry out the basic function (Gronauer et al., 2016; Terninko et al., 1998). Figure 5 is a parcelled system of the device into an extended model of the functions of the technical device.

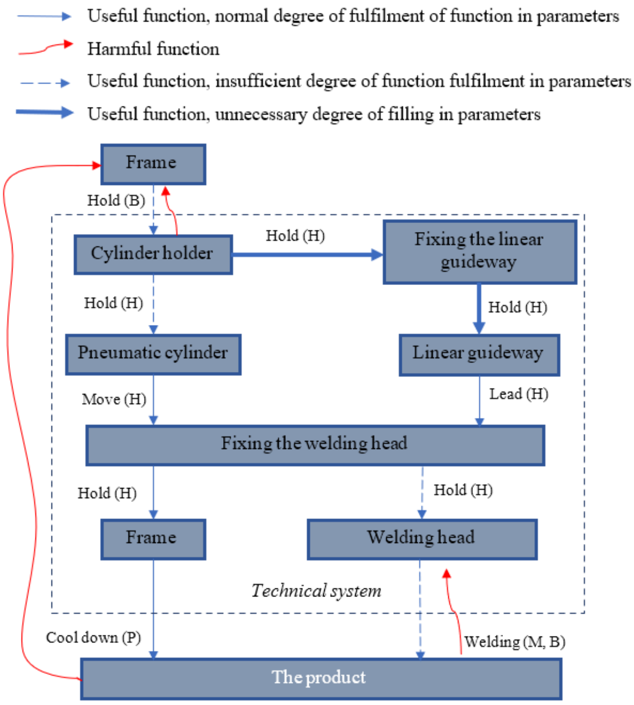

Fig. 5. Technical system of the assembly node for one-point fixing

Based on this model, we know that some structural elements of the attachment perform a function with insufficient filling and others with unnecessary filling. Therefore, our optimization should focus on this element or these elements of the fixing structure.

Thanks to a detailed analysis of the technical node, we found out or determined "What?" and "Why?" we will innovate. The next step is determining "How?" we will innovate (Table 1). Generalized shortcomings (need to eliminate):

- Low stiffness of welding assembly attachment.
- Low setting variability.
- Mounts are only suitable for one type of welding assembly.
- Low variability when combining different types of welding sets is necessary.
- Complex structure for assembly, production, and subsequent maintenance

Table 1. List of assignments and proposed solutions

Assignment	Solution design
Harmful functions	
How to increase the stiffness of the attachment?	Change of the design of the handle.
Functions with insufficient fulfilment	
How to increase the efficiency of the welding process?	Precise guidance to the place of welding. Changing the material of the attachment elements.
Functions with an unnecessary degree of fulfillment	
How to eliminate unnecessary elements of the mounting structure?	To unify the attachment of assembly nodes. Unify the attachment elements.

2.2. ARIZ and technical contradiction

Based on the analyses, it was possible to identify and describe the undesirable effects of optimized technical systems. By gathering information and analyzing it, the picture of the problem became clearer. It was possible to propose optimization solutions to a certain extent. The tasks described can be divided into two groups (Table 2) according to the difficulty:

- Trivial assignments- these are simple assignments and do not require any solving methods to solve them.
- Problem assignments-these are complex assignments, and the ARIZ solving method is used to solve such assignments within TRIZ.

Table 2. Distribution of assignments

Trivial assignments	Problem assignments
How to eliminate unnecessary elements of the mounting structure? How to reduce the weight of the assembly node?	How to increase the grip strength? How to increase the variability of the attachment? How to ensure the compatibility of the attachment of welding assemblies?

To accurately determine the technical discrepancy, it is advisable to name each deficiency with one word or as simply as possible. For this case, we can call the insufficient parameters we want to improve as strength, adaptability, and complexity of construction (Table 3).

When looking for a solution to technical contradictions, we can help Altshuller table of typical technical contradictions, which contains various solving methods for overcoming these contradictions. The resolution of all technical conflicts may consist of different procedures/methods. The solution procedure/method "Principle of Dynamism" forms their intersection. The principle of Dynamism:

- The characteristics of the object (load, dimensions, shape, state of matter, temperature, colour, etc.) or the external environment must be changed to have optimal values in each phase of the process.
- Divide the object into parts capable of moving about each other.
- If the object is immobile, it must be made mobile and capable of being moved (Altshuller, 1999).

Table 3. Description of technical contradictions

Technical contradiction 1	Technical contradiction 2	Technical contradiction 3
By increasing the complexity of the construction of the attachment of the welding assembly, its overall strength will decrease.	Increasing the complexity of the sonotrode mounting design reduces adaptability. There is no possibility of using the structure for another type of welding assembly.	To some extent, the complexity and adaptability of the weld assembly's design can grow together only up to a certain limit. However, at their expense, the strength of the structure will decrease.
↑ Complexity ↓ Strength	↑ Complexity ↓ Adaptability	↑ Complexity Adaptability ↓ Strength

2.3. New design of the assembly node

The analysis of the elements and structures of the assembly node system showed us into which subsystems the components are divided, namely:

- Subsystems of welding assemblies.
- Subsystems for fastening welding assemblies.
- Drive and guidance subsystems.

We will also adhere to this division when designing the new assembly node. Most elements of welding assemblies are purchased parts. Based on the manufacturer's recommendations, it is recommended to assemble parts only with components produced by the given manufacturer. For this reason, parts of the subsystem of welding assemblies will not be subject to optimization. We will take these parts as dimensionally invariant; therefore, their grasping possibilities are also limited. The subsystems of the fixing of the welding assemblies and the drive subsystems need to be optimized to the greatest extent.

2.3.1. Drive and guideway subsystem

From the model of the functions of the technical system, it emerged that pneumatically the cylinder does not fulfil the required function sufficiently. Linear guideways have taken over part of their functions. The new solution works with both elements as if they were one whole. One element without the other loses its role within the technical system. Storing both elements in one technical subsystem increases the rigidity of the technical system as a whole (Figure 6).

The part of the structure to which other systems will be fixed has substantially changed. The newly designed construction is now more variable. The part intended for additional mounting provides several mounting positions for the subsystems. Several options exist for fixing welding assemblies to the pneumatic cylinder and linear guide subsystem (Figure 7).

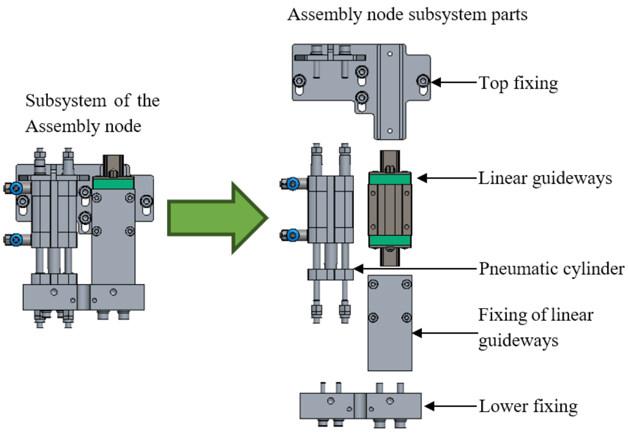

Fig. 6. The proposal of merging a pneumatic cylinder with linear guidance into a whole

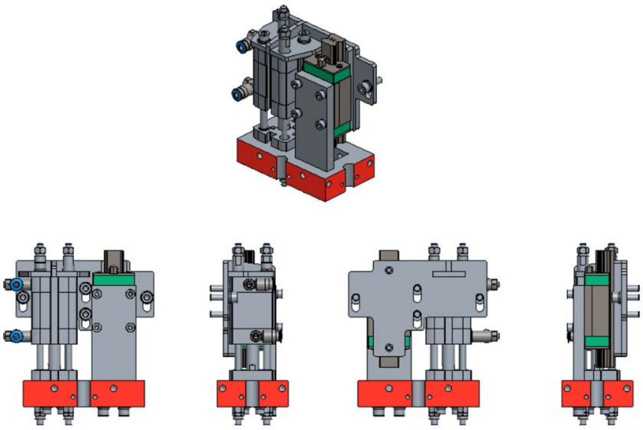

Fig. 7. Areas intended for anchoring subsystems (highlighted in red)

2.3.2. Design of the welding assembly fixing subsystem

When designing the construction of clamping subsystems, we must consider both variants of clamping welding assemblies. This subsystem is between the welding assembly subsystem and the propulsion subsystem. At the same time, the linear guideway forms a connecting link to create a technical system of assembly nodes (Figure 8 and Figure 9).

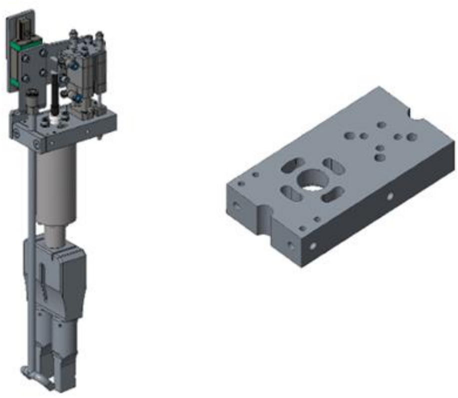

Fig. 8. One-point fixing of the welding assemblies

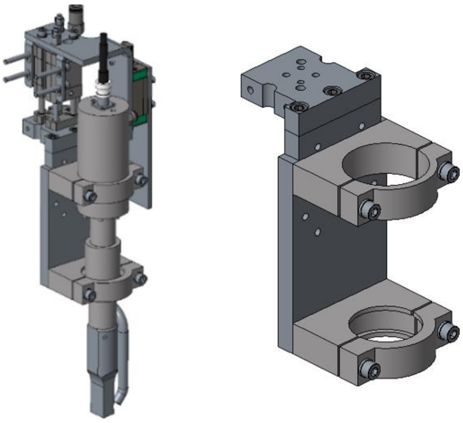

Fig. 9. Two-point fixing of the welding assemblies

2.3.3. Design of a one-point subsystem for fixing the welding assembly

This type of fixing uses only the upper part of the body of the welding assembly. The upper part of the ultrasonic transducer serves to fix it in the correct position to the welded parts. The ultrasonic transducer has mounting holes for M5 screws in its upper part. The original clamping member had the task of connecting the pneumatic cylinder to the welding assembly. His next task was to fix the cooling tube and, after completing the linear guide, also fix the linear guide carriage. We will use the unfolding technique for this member and transfer some of the tasks of this member of the structure to another member (Figure 10).

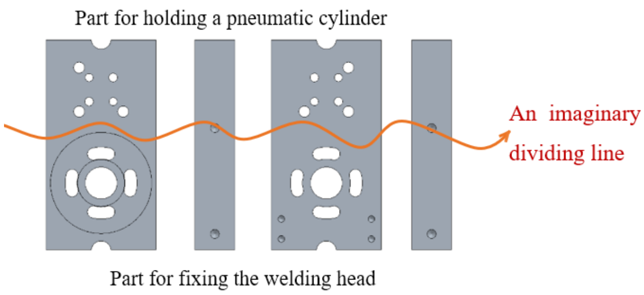

Fig. 10. Proposal of the development of the fixing member

By unfolding one of the original clamping members, we can delegate the clamping function of the pneumatic cylinder and the clamping function of the linear guide carriage. The cooling tube can be fixed to the drive and line subsystem. An alternative to this would be to fix a new welding assembly subsystem. The new subsystem of fastening the welding assembly will therefore have two functions. The primary function will be to hold the welding assembly, and the secondary function will be to keep the cooling tube (Figure 11).

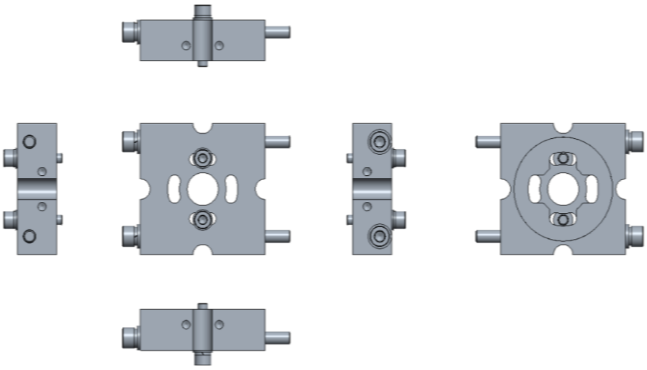

Fig. 11. New subsystem of one-point fixing of the welding head

2.3.4. Design of a two-point subsystem for fixing the welding assembly

This type uses two parts of the welding assembly for fixing. The upper part is joined to the ultrasonic transducer, and the lower part is fixed to the booster's ring.

The original design included directly mounting the fixing subsystem and welding machine on the pneumatic cylinder. The cooling tube could be additionally fixed to the pneumatic cylinder and provide cooling. In addition to the need to strengthen the structure, the requirements also resulted in a new function for grasping a part of the linear guide. We will transfer some tasks of this structure member to another member or another subsystem of the structure (Figure 12). We can also use the unfolding technique for this member.

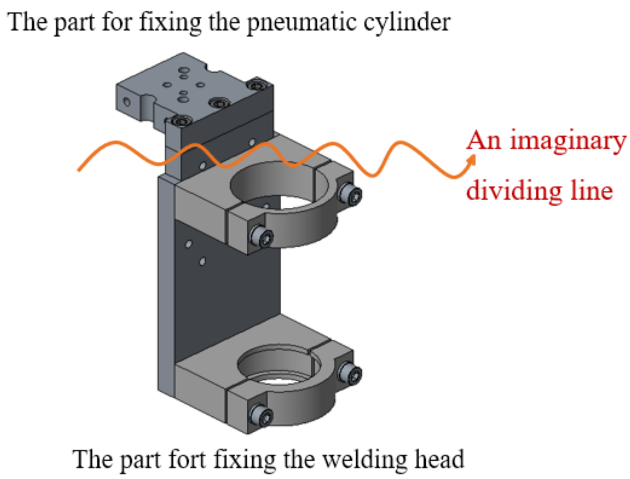

Fig. 12. Proposal for the development of the two-point fixing subsystem

After developing the original fixing subsystem, we will move the pneumatic cylinder attachment function and the linear guide carriage fixing function to the drive and guidance subsystem. The process of gripping the cooling tube passes to the subsystem of the sofa and the line. Therefore, the new subsystem of fixing the welding assembly only has the function of fixing the welding assembly in the desired position (Figure 13).

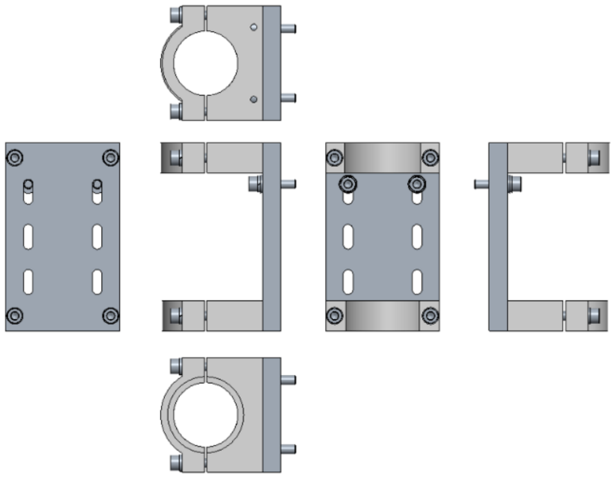

Fig. 13. Design of the subsystem of the two-point fixing of the welding assembly

Although we did not fundamentally reduce the construction's complexity, we managed to increase the variability of the fixing.

2.4. Optimized assembly node

Using the TRIZ method and the results of testing prototype devices, we worked on optimized/new designs of subsystems of assembly nodes. By assembling optimized sub-systems, we can get different variants of the given technical system as needed. Variability in assembly nodes' assembly has also increased with the option of choosing a drive and line subsystem (Figure 14).

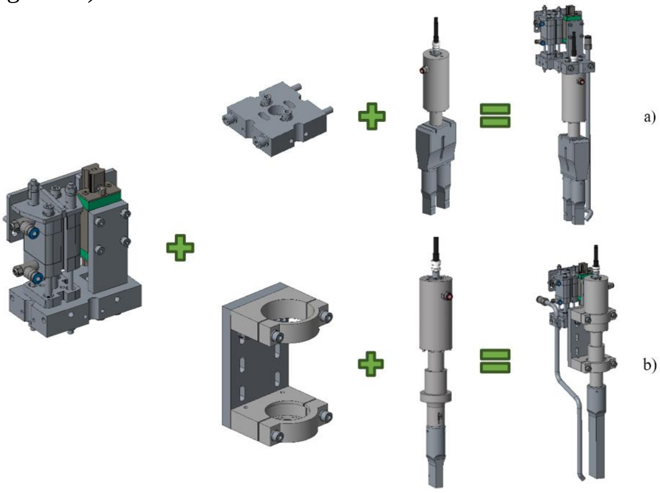

Fig. 14. Compilation of optimized assembly nodes
a) one-point fixing; b) two-point fixing

The new drive and guide subsystem allow both welding heads to be held in four positions. For the two-point fixing, the possibility of setting different heights of the welding assembly in a vertical position has been added. The variability of the mounting of the cooling tubes has also increased significantly. This increased the variability of assembly nodes even more significantly. In the new structural design of the unified assembly node, in which the manufactured subsystem of the drive and line for both types of ultra-sonic welders is used, there are:

- One type of linear guideway.
- One type of pneumatic cylinder.
- Nine types of welding sets.
- Ten manufactured parts.

2.5. FME analysis of assembly node

Using the finite element method was made a comparison between old and new (optimized) construction. The goal was to determine how the behaviour of selected assembly nodes changed under load. The authors performed the software analyses in the ANSYS WORKBENCH program. In simulated models were removed all redundant elements with secondary functions were. The simulations were assigned the gravitational force and the pressure force (acting in the opposite direction to the gravitational force). Pressure forces during ultrasonic welding are from 0.2 MPa to 10 MPa. The method of choosing the pressure value depends primarily on the properties of the material to be welded. (Kuo et al. 2022; Li et al. 2019)

For ultrasonic welding of plastics, the pressure most often ranges from 0.2 MPa to 0.3 MPa. It is always necessary to test the given force in the device and adjust it according to the quality of the test welds. Based on the recommendation of the sonotrode manufacturers, a pressure of 3 MPa will be considered at the beginning and later with an operating pressure of max. 0.3 MPa. The total welding time must be divided into welding and material solidification time. In the simulation, the welding time was set to 1 second, and the solidification time was set to 1 second. The essential condition for the analyzed structures is that the welding tip does not deviate by a maximum of 1 mm at the weld point. The second condition is that the mechanical stress does not exceed the yield strength of the given steel.

We subjected the original one-point and two-point holders to FEM analyses. Because of the large number of results and different variants, the results are presented only for one-point attachment before optimization.

The results in Figures 15 and 16 are at 3 MPa and 0.3 MPa pressure. Figure 15 is the design of the one-point fixing node P01. Figure 16 shows the creation of the one-point fixing node S01. From the point of view of the different solutions of the mounting design, the results of the analyses were an interesting option for presentation and comparison.

The higher load (3 MPa) pointed to critical points in the structure. As mentioned earlier, the mounting method turned out to be insufficient. It can be argued that both designs showed signs of excessive deformation of the mounting at a higher load (3 MPa). The lower load analyses (0.3 MPa) conducted for individual structures in Figures 17 and 18 did not reveal any significant deviations and critical stresses. In addition, the mounting nodes met specific requirements.

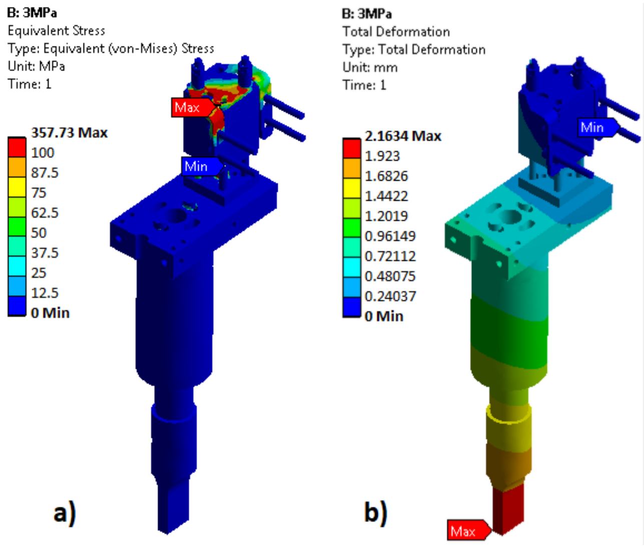

Fig. 15. One-point fixing on the montage node variant P01 (3 MPa) a) Equivalent (Von-Mises) stress b) Maximal deformation of tip

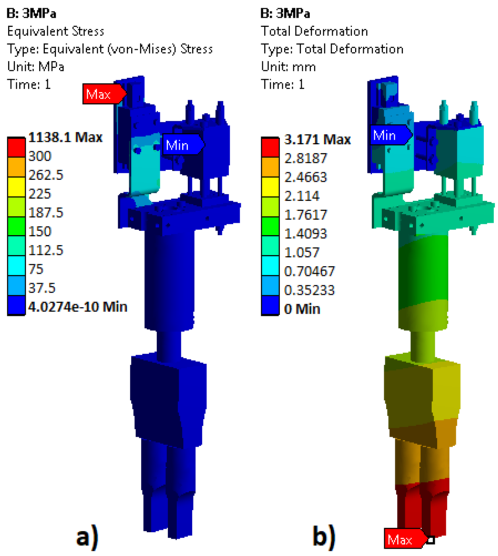

Fig. 16. One-point fixing on the montage node variant S01 (3 MPa) a) Equivalent (Von-Mises) stress b) Maximal deformation of tip

The fasteners show high-stress values at a higher load (3 MPa), significantly affecting the device's functionality. The analysis itself pointed to the components that are critical parts of our construction. The FEM analysis showed that the prototypes had a problematic part without a linear guideway. From a design point of view, the pneumatic cylinder was chosen incorrectly. The occurrence of high stresses on the fixing and the lack of an auxiliary function for moving the assembly node downwards caused backlash, stresses, and inaccuracies.

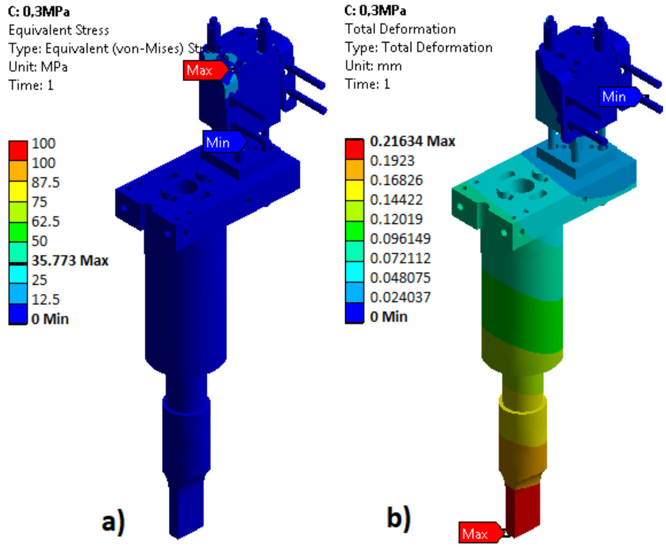

Fig. 17. One-point fixing of the montage node variant P01 (0.3 MPa) a) Equivalent (Von-Mises) stress b) Maximal deformation of tip

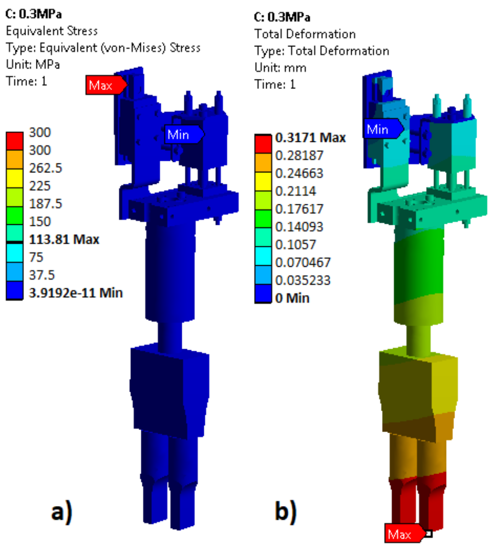

Fig. 18. One-point fixing of the montage node variant S01(0.3 MPa) a) Equivalent (Von-Mises) stress b) Maximal deformation of tip

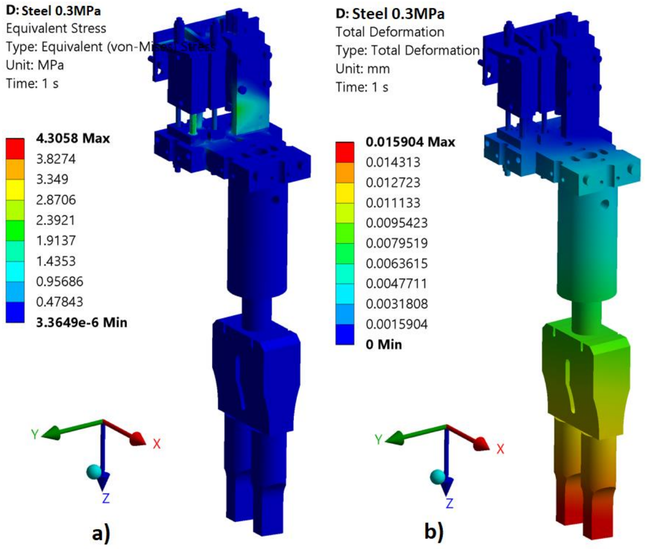

Fig. 19. Optimized one-point fixing of montage node 106-X5-01_0100 (0.3 MPa) a) Equivalent (Von-Mises) stress b) Maximal deformation of tip

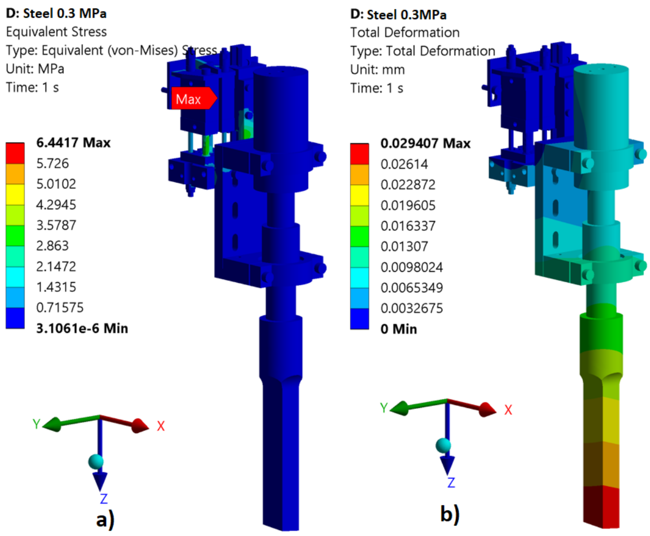

Fig. 20. Optimized two-point fixing of montage node 106-X5-01_0200 (0.3 MPa) a) Equivalent (Von-Mises) stress b) Maximal deformation of tip

The design was optimised using the TRIZ methodology at the end of the improvement requirement. In Figures 19 and 20, the results of FEM analyses can be seen at a load of 0.3MPa. Figure 19 shows the optimised design of the 106-X5-01_0100 one-point fixing. Figure 20 shows the optimised design of the 106-X5-01_0200 two-point fixing. The main requirements for the optimised design were the maximum deflection of the welding tip up to 1mm and the mechanical tension in the structure did not exceed the yield limit for S235 JGR 1 steel.

The FEM analysis shows that the optimised design of the construction of the assembly node is suitable. The original building was unsuitable and excessively stressed. Comparing similar studies before and after optimising the structure from the point of view of functionality was the improvement of properties achieved. We have suitably optimised the design.

2.6. Modal analysis

We have analysed the natural frequencies of the construction from steel for the selected fixings of the welding assemblies. Significant in this section is the comparison of the natural frequency with the welding frequency, to which we add the deviation for the given frequency. At welding frequencies of 30000Hz, a variation of +150 Hz was chosen. Frequency 30150Hz (f_c) was selected as the comparison frequency. Table 4 shows the results of modal analysis and a comparison of maximal modal frequency (f_{max}), and minimal modal frequency (f_{min}) ranges with the comparative frequency f_c.

Table 5. Comparison of construction variants of assembly nodes

Assembly Node	f_c [Hz]	f_{max} [Hz]	f_{min} [Hz]	Verify (Yes/No)
106-X5-01-0100	30150	30188	29933	Yes
106-X5-01-0200	30150	30226	29800	Yes

3. Results and Discussion

The task of the construction team was to optimize the design of special-purpose devices. The TRIZ was chosen for optimization activity. Part of the methodology was the process of deep analysis (FNA), which was followed by the process of simplification and rationalization of the existing structure. The procedures were followed by utilising the ARIZ methodology and solving important structural contra-dictions. The TRIZ methodology led the design team to the desired results.

The optimization process was carried out due to the functionality of the devices. The device performed its function insufficiently. On both prototype devices, fifty-two different manufactured parts, one type of linear guide, and a pneumatic cylinder were used to hold nine welding assemblies. Optimization and, above all, simplification were necessary. In the optimized structural design, we used only ten different manufactured parts, one type of linear guide and one type of pneumatic cylinder to hold the same number of welding assemblies (Table 5).

Table 5. Comparison of construction variants of assembly nodes

Variant of assembly node	Quantity of welded assemblies	Quantity of manufactured parts
Original fixing	9	52
Optimized fixing	9	10

The presented software analyses show that all optimized and alternative designs of mounting nodes for ultrasonic welding should strength-comply with the requirements of the optimized equipment. We can verify the confirmation of the results from a practical point of view by the test operation of the presented devices. Using the optimization process, we have increased the ability to function properly.

By making the assembly nodes lighter, we can improve the final design. It depends on the design team's consideration. A consultation within the group is required to change the material. Some components are not suitable for this process from a structural point of view. We could produce less stressed parts from aluminium alloy. It would be necessary to apply loads and FEM analyses to verify that the component(s) in question meet the design requirements for verification. An important aspect is whether the parts would meet the safety requirements (loosening/pulling out of screws, thread wear, fit wear, etc.).

The use of ultrasonic welders has a considerable impact on the very construction of the device, such as collisions in the structure, junction permitting, etc. The excitation of different frequencies from the ultrasonic welding process seems to be a potentially questionable part of the assembly nodes. The frequencies themselves can negatively affect the need for maintenance and the cost-effectiveness of the device.

4. Summary and Conclusion

The biggest challenge for the technological systems with ultrasonic welders proved to be the design of sufficiently strong and, at the same time, flexible mountings of welding heads. An essential part of the presented problem was the solution to the variability of fixing. One of the main requirements was the applicability of mounting nodes in other series of similar devices.

The design team established the TRIZ methodology as the principal solving method. The analytical part of the methodology (FNA analysis) determined the design nodes that cause problems and need improvement. Subsequently, a way to improve the existing structure was determined using the ARIZ methodology. The new structural designs, together with the original designs, were subjects for FME analysis. Some of the mentioned nodes have been selected in the article and can be seen in chapter 2.5.

The design optimization process provided an improved and streamlined design that met the requirements with its variability and functionality. The most important goal was to make the structure operational, along with the rationalization of the mounting nodes. These objectives have been achieved and must be verified by prototypes produced and tested by prototypes.

Knowing the procedures and functions provided by the TRIZ method allows the designer to solve a specific technical problem methodically and often successfully. However, applying this methodology is not only in a technical direction; its techniques are successfully used to optimize various branches of business, IT, and economics. Due to its effectiveness, the TRIZ methodology can also be used to address reducing human factor problems.

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Reference

Akay, D., Demıray, A., Kurt, M., 2008. Collaborative tool for solving human factors problems in the manufacturing environment: The Theory of Inventive Problem Solving Technique (TRIZ) method. International Journal of Production Research, 46(11), 2913-2925, DOI: 10.1080/00207540600969774

Altshuller, G., 1999. The Innovation Algorithm: TRIZ, systematic innovation and technical creativity, first ed. Technical Innovation center, Worcester, Massachusetts, USA.

Bhudolia, S.K., Gohel, G., Leong, K.F.,Islam, A., 2020. Advances in Ultrasonic Welding of Thermoplastic Composites: A Review, Materials, 13(6), 1284, DOI: 10.3390/ma13061284

Bultey, A., Yan, W., Zanni, C., 2015. A Proposal of a Systematic and Consistent Substance-field Analysis. World Conference: TRIZ FUTURE, TF 2011-2014, Elsevier Procedia, 701-710.

Čačo, M., Kohár, R., Hrček, S., Tribula, R., Ščerba, P., 2017a. Use the Method of TRIZ in Optimizing Automated Machine for Ultrasonic Welding. 12th International Scientific Conference of Young Scientists on Sustainable, Modern and Safe Transport Location, High Tatras, Slovakia, Elsevier Procedia, 80-85.

Čačo, M., Tribula, R., Ščerba, P., Kohár, R., 2017b. Application of simulation software to optimize construction nodes of ultrasonic welding machines. 58th International Conference of Machine Design Departments, Czech University of Life Sciences, Prague, Czech Republic, 56-59.

Chechurin, L., Borgianni, Y., 2016. Understanding TRIZ through the review of top cited publications. Computers in Industry, 82, 119-134, DOI: 10.1016/j.compind.2016.06.002

EMERSON, 2023. "Ultrasonice Metal Welding", available at: https://www.emerson.com/sk-sk/automation/welding-assembly-cleaning/metal-welding (accessed 20 February 2023)

Fang, Y., Yamamoto, T., Komarov, S., 2018. Cavitation and acoustic streaming generated by different sonotrode tips. Ultrasonics Sonochemistry, 48, 79-87, DOI: 10.1016/j.ultsonch.2018.05.011

Fiorineschi, L., Frillici, F.S., Rotini, F., Conti, L., Rossi, G., 2021. Adapted Use of the TRIZ System Operator. Applied Sciences, 11(14), 6476, DOI: 10.3390/app11146476

Gallego-Juarez, J. A., Graff, K.F., 2014. Power Ultrasonics: Applications of High-Intensity Ultrasound, first ed. Woodhead Publishing, Oxford, United Kingdom.

Gronauer, B., Nähler, H.T., 2016. TRIZ-Supported Development of an Allocation System for Sheet Metal Processing. Research and Practice on the Theory of Inventive Problem Solving (TRIZ), 169-185, DOI: 10.1007/978-3-319-31782-3_10

Gupta, K., Davim, P.J., 2021. Advanced Welding and Deforming (Handbooks in Advanced Manufacturing), first ed. Elsevier.

Hipple, J., 2005. The Integration of TRIZ with Other Ideation Tools and Processes as well as with Psychological Assessment Tools. Creativity and innovation management, 14(1), 22-33, DOI: 10.1111/j.1476-8691.2005.00322.x

IPASlovakia, 2017. "TRIZ - Creation and solution of innovative assignments", available at: https://www.ipaslovakia.sk/clanok/triz-tvorba-a-riesenie-inovacnych-zadani (accessed 19 February 2023)

Kaplan, S., 1996. An Introduction to TRIZ, Ideation International Inc. Farmington Hills, Michigan, USA.

Katolický, Z., Bušov, B., Bartlová, M., 2014. Turbojet engine innovation and TRIZ. 16th International Conference on Mechatronics - Mechatronika 2014, Brno, Czech Republic, IEEE, 16-23.

Kuo, C.C., Tsai, Q.Z., Li, D.Y., Lin, Y.X., Chen, W.X., 2022. Optimization of Ultrasonic Welding Process Parameters to Enhance Weld Strength of 3C Power Cases Using a Design of Experiments Approach. Polymers, 14(12), 2388, DOI: 10.3390/polym14122388

Kuratani, F., Miyano, S., Yoshida, T., Washio, S., 2019. Effect of contact area with fixture on dynamic behaviour of joint interface in ultrasonic welding of thermoplastics. Thirteenth International Conference on Recent Advances in Structural Dynamics, Valpre, Lyon, France, IOP Publishing, Journal of Physics: Conference Series 1264th ed., Vol. 012047

Li, H., Cao, B., 2019. Effects of welding pressure on high-power ultrasonic spot welding of Cu/Al dissimilar metals. Journal of Manufacturing Processes, 46, 194–203, DOI: 10.1016/j.jmapro.2019.07.018

Mongan, P.G., Modi, V., McLaughlin, J.W., Hinchy, E.P., O'Higgins, R.M., O'Dowd, N.P., McCarthy, C.T., 2022. Multi-objective optimisation of ultrasonically welded dissimilar joints through machine learning. Journal of Intelligent Manufacturing, 33(4), 1125–1138. DOI: 10.1007/s10845-022-01911-6

NOTUS, 2023. "Ultrasonic welding? Yes, this technology can do that too", available at: https://www.notus.sk/blog/zvaranie-ultrazvukom-ano-aj-to-tato-technologia-dokaze (accessed 19 February 2023)

Orloff, M.A., 2010. Inventive Thinking through TRIZ: A Practical Guide. Second ed. Springer Berlin Heidelberg, Germany.

Palčák, F., 2016. Improvement of Dynamic Characteristics of the Car in the Light of Technological Evolution. XII International Conference on the Theory of Machines and Mechanisms, Liberec, Czech Republic, Springer Cham, 391–397.

Rantanen, K., Domb, E., 2007. Simplified TRIZ: New Problem Solving Applications for Engineers and Manufacturing Professionals, second ed. Auerbach Publications, Boca Raton, Florida, USA.

Sahoo, S.K., Satpathy, M.P., 2020. Ultrasonic Welding of Metal Sheets, first ed., CRC Press, Boca Raton, Florida, USA.

Shu, K.M., Wang, Y.J., Chi, C.W., 2013. The Design of Multiple Function Acoustic Horns for Ultrasonic Welding of Plastic. Applied Mechanics and Materials, 479-480, 329–332. DOI: 10.4028/www.scientific.net/amm.479-480.329

Skařupa, J, 2007. Creativity and innovation thinkinking (Kreativita a inovační myslení v konstruování), Ediční středisko VSB TUO, Ostrava, Czech Republic.

Terninko, J., Zusman, A., Zlotin, B., 1998. Systematic Innovation: An Introduction to TRIZ (Theory of Inventive Problem Solving), first ed., CRC Press, Boca Raton, Florida, USA.

Tomašiková, M., Tropp, M., Gajdošík, T., Krzywonos, L., Brumerčík, F., 2017. Analysis of Transport Mechatronic System Properties. 12th International Scientific Conference of Young Scientists on Sustainable, Modern and Safe Transport Location, High Tatras, Slovakia, Elsevier Procedia, 881-886.

Tropp, M., Brumerčík, F., Šteininger, J., Weis, P., Glowacz, A., 2018. Heat distribution in the deep drawing device components working by high temperatures. The 10th International Symposium Machine and Industrial Design in Mechanical Engineering, Novi Sad, Serbia, IOP Science 393, 012075.

Tropp, M., Tomašiková, M., Bašťovanský, R., Krzywonos, L., Brumerčík, F, 2017. Concept of Deep Drawing Mechatronic System Working in Extreme Conditions. 12th International Scientific Conference of Young Scientists on Sustainable, Modern and Safe Transport Location, High Tatras, Slovakia, Elsevier Procedia, 893-898.

Troughton, M.J., 2008. Handbook of Plastics Joining: A Practical Guide (Plastics Design Library), second ed. William Andrew Norwich, New York, USA.

Wang, X., Song, J., Liu, J., Wang, Z.L., 2007. Direct-Current Nanogenerator Driven by Ultrasonic Waves. Science 316(5821), 102-105, DOI: 10.1126/science.1139366

Zhang, C., Li, H., Liu, Q., Huang, C., Zhou, K., 2022. Ultrasonic Welding of Aluminum to Steel: A Review. Metals, 13(1), 29, DOI: 10.3390/met13010029

使用 TRIZ 方法优化自动化工作场所的装配设备

關鍵詞
超声波焊接
优化
特里兹
蒙太奇节点
有限元分析

摘要

本文介绍的文章使读者熟悉超声波焊接机工作场所的优化过程 文章的主要部分涉及原型，其构造不符合生产、经济和功能的要求。测试运行指出了缺点和不准确之处。 施工团队将使用其中一种**众**所周知的优化和设计方法。 这就是 TRIZ 方法（创建和解决创新任务）。 上述方法将**两个**强大的工具合二为一。 具体来说，就是功能与成本分析（FNA）和解决创造性任务的算法（ARIZ）文章描述了使用该方法更详细地解决结构中有问题的部分。优化过程的结果是一个新的改进结构，其刚度方面的属性也通过 ANSYSWorkbench 程序中的仿真得到确认。 优化部件的使用也将在其他类似设备中使用。该研究将跟进一系列新的超声波焊接机的设计。