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# USING THE IDEA DIAGRAM METHOD TO DESIGN A DEVICE TO RECORD THE VARIATION OF FORCE SIZE IN SHEAR CUTTING

**Rica Georgiana BÂZDÂGĂ, Gheorghe NAGÎȚ, Alexandra-Anamaria SPIRIDON, Andrei Marius MIHALACHE, Oana DODUN, Laurențiu SLĂTINEANU**

***Abstract:*** *The existence of information regarding the behavior of different materials under mechanical stress is useful when aiming to optimize the conditions for the shearing conditions of workpieces made of metallic or plastic materials. The paper addresses the problem of designing a device that would allow the experimental study of the behavior of different materials during shearing. To identify a solution for such a device, a method to stimulate technical creativity was used, namely the idea diagram method. By applying the principles related to this method, a device designed to allow the study of the behavior of materials during shearing was gradually outlined. The device can be adapted to a universal lathe and provides conditions for highlighting the influence exerted by different factors on the variation of the magnitude of the force necessary for the materialization of a shearing process.*

***Keywords:*** *shearing process, shearing forces, evaluation of the force variation, idea diagram method, universal lathe device.*

## 1. INTRODUCTION

In machine manufacturing, processes can be classified according to changes in the mass of the workpiece: processes without mass change, subtractive processes based on material removal, and additive processes based on the addition of material. This classification reflects the type of transformation the workpiece undergoes and helps in selecting the appropriate technologies for specific product requirements. Subtractive processes include cutting, erosion, and stamping, where material is precisely removed to obtain the desired shape.

*Shear cutting* is a material separation process in which tangential forces are applied by two cutting elements in relative motion. The mechanism relies on exceeding the material's yield strength in the contact zone, leading to a controlled fracture with minimal chip formation. Accurate determination of the required shearing force is crucial for the proper design of equipment and ensuring efficient, high-quality processing. This information supports the optimization of technological parameters, reduces tool wear, prevents surface defects, and enhances process safety and reliability. For a better understanding of the factors capable of affecting the magnitude of the shear force, the results of several studies undertaken in this direction are highlighted below.

Lokshin et al. [1] have emphasized the importance of considering shear in structural analysis. Using the straight-line hypothesis, they show that neglecting shear stresses could lead to underestimated deformations and buckling loads, especially in thick structures. Including shear in structural analysis can improve the accuracy of predictions in complex systems.

Chen [2] investigated the effect of central holes on the shear behavior of steel plates. The study revealed a notable reduction in shear strength due to the holes, but plate-type reinforcements effectively restored load-bearing capacity. The proposed analytical models aligned well with experimental results, validating their use in structural assessment.

Prisăcaru [3] studied silicon under scratching, simulating microshearing, and showed that controlled force induces elastic, plastic, and amorphous transitions. Accurate force control is key to precision in micromachining.

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Pop [4] examined composite reinforcement in masonry and concrete structures, finding that such systems improve shear force distribution, increase load capacity by up to 30%, and reduce the risk of cracking. The study leads to the conclusion that modern rehabilitation is effective for controlling shear processes.

Rus [5] studied the behavior of brake pads made of composite materials under braking loads, showing that ceramic or metallic additives improve shear strength, wear uniformity, and extend the service life of brake pads by up to 40%. The stable behavior of these materials under cyclic mechanical loads recommends them for use in the railway field.

Munteanu et al. [6] investigated the shear and compression behavior of perforated metal columns, identifying possibilities for a 15% reduction in the shear strength offset by a 20% material saving. The results suggested a feasible compromise between structural strength and cost efficiency.

The mind map method belongs to the broader class of mind mapping methods, which visually structure and generate useful information in design activities. Proven effective in areas such as education, research, and decision-making, mind mapping is preferred as a working method by some researchers. Thus, Elmeshai [7] showed that mind mapping improves design efficiency and creativity, helping teams define clearer objectives and develop more coherent solutions by revealing the interconnections between system components.

Palaniappan et al. [8] used mind maps to teach skin lesion morphology, observing improved student performance in recognition and classification processes. The study supports the application of mind maps in visually demanding subjects.

Kalyanasundaram et al. [9] found that mind maps can improve the retention and application of information by medical students, leading to better academic performance through improved cognitive processing.

Crow and Sheppard [10] highlighted that mind maps are a valuable tool in social science research, helping to improve qualitative analysis and formulate clearer conclusions.

This study aims to lead to the identification of a device for tracking cutting force using the mind map method. The study includes an analysis of some works that address issues regarding cutting force determination, a summary of the use of the mind map method in design, and proposes a conceptual solution for monitoring force variations in materials characterized by low resistance to mechanical stress.

## 2. SHEAR CUTTING

*Shearing* is a fundamental process in the manufacturing industry, which involves the separation of a portion of the material of the semi-finished product by the application of a force by two cutting elements, a punch and an active plate, which move relative to each other under conditions of small clearance. Shearing is commonly used in sheet metal cutting processes and in the processing of various other types of workpieces. The importance of the shearing process lies in its high efficiency, good dimensional accuracy under specific conditions, and its suitability for integration into automated production lines [11-14].

From a theoretical point of view, the magnitude of the force required to perform the shearing process can be estimated, as a first approximation, using a simplified relationship that correlates the mechanical properties of the material with the dimensions of the required area. Thus, the shearing force can be expressed by the relationship:

$$F_f = \tau \cdot A, \tag{1}$$

where $F_f$ denotes the shearing force, $\tau$ is the shear strength of the material, and $A$ represents the area of the sheared section. In the case of workpieces with a rectangular cross-section, the sheared area can be expressed as:

$$A = b \cdot t, \tag{2}$$

where $b$ is the width of the sheared zone, and $t$ represents the thickness of the workpiece [11-14].

The shearing process follows a defined sequence of phases: positioning the workpiece between the punch and the active plate, applying the cutting force, initial plastic deformation,

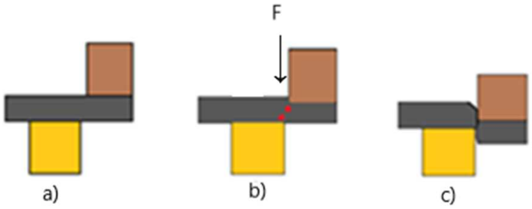

Fig. 1. Phases of a shearing process: a – achieving contact between the workpiece and the tools; b – the appearance and propagation of cracks; c – the actual separation of a part of the workpiece

crack initiation, crack initiation and part separation (Fig. 1). Each phase contributes to the overall efficiency of the process, and its execution directly affects the quality of the final product. Key output parameters include cutting force, cut surface quality, burr size and shape, dimensional accuracy, and productivity. These indicators serve as benchmarks for evaluating the performance and stability of the shearing process in industrial applications. A thorough understanding of each phase allows engineers to optimize process parameters for different materials and use cases.

The output parameters of the shearing process are influenced by multiple factors, including the material's properties (such as hardness and compression strength), workpiece dimensions, cutting speed, tool geometry and wear, the type and characteristics of lubricants used, and the rigidity of the workpiece clamping system. Precise control of these variables enables process optimization and consistent performance. Furthermore, modern simulation tools allow for accurate prediction of material behavior, contributing to increased efficiency and sustainability in shearing operations.

Several hypotheses from the specialized literature address the evolution of shear force, including its increase with workpiece thickness, the existence of an optimal clearance between tool elements to minimize force magnitude, and the influence of cutting speed on crack initiation and propagation. Validating these hypotheses supports the development of predictive models essential for shearing process design. Such models are particularly important when adapting the shearing process to advanced materials, such as composites or high-strength alloys, commonly used in aerospace, automotive, and medical industries, where precision and repeatability are critical.

## 3. IDEA DIAGRAM METHOD

*The mind map method* could be considered as a qualitative instrument used for research and analysis, situated within the broader category of visual and heuristic methodologies. Unlike quantitative techniques, mind mapping focuses on exploring, organizing, and visually representing complex conceptual relationships through non-linear associations. This visual approach encourages critical reflection, systemic exploration, and creative problem-solving, proving to be highly effective in both academic research and educational contexts.

Initially developed to enhance the capabilities of visual thinking and to provide more intuitive structures for knowledge representation, the method gained widespread attention in the 1970s through the work of Buzan, who introduced and promoted mind mapping as a cognitive tool. Concurrently, Novak contributed to the refinement of concept mapping within educational settings, further solidifying the value of such techniques in structured learning environments.

The mind map method involves a systematic and visual approach, structured in several essential steps, which facilitates the clarification and deepening of the analyzed subject [15-17]:

- Establishing the central theme – clearly and concisely stating the research topic, placed in the center of the diagram;
- Generating main ideas – identifying major directions of analysis, which branch off from the central theme;
- Developing secondary ideas – detailing each main idea with sub-concepts, examples, or explanations;
- Logically connecting elements – tracing relationships between concepts through arrows or symbols indicating logical, causal, or hierarchical links;
- Revising and completing the diagram – checking the overall structure, adding or

adjusting components for clarity and completeness.

*The idea diagram method* can be considered as a particularization of the mind map method for revealing the component variants of an object or ensemble. In the last decades of the previous century, Professor Vitalie Belous promoted the idea diagram method as a useful tool in terms of stimulating the technical creativity of innovative people [15-17]. Its utility was also emphasized in collaborative environments, where it enhanced group brainstorming and facilitated the rapid development of structured concepts and prototypes. In engineering, the idea diagram method was often used in product development stages (from requirements definition to functional decomposition), helping teams avoid tunnel vision and identify trade-offs.

Furthermore, the method allowed for efficient documentation of thought processes and design decisions, providing a traceable logic path that can support later iterations or team transitions. This quality is especially valuable in academic and industrial research environments, where reproducibility, transparency, and interdisciplinary collaboration are increasingly important.

## 4. DEVELOPMENT OF AN IDEA DIAGRAM FOR A DEVICE INTENDED TO MONITOR THE VARIATION OF THE FORCE MAGNITUDE DURING SHEAR CUTTING

The development of a device capable of capturing the variation in shear force magnitude requires a structured, systematic, and iterative design approach. The idea diagram method was selected as a methodological tool due to its ability to logically organize technical concepts and generate multiple solution pathways for each component of the system. Its application is justified by the exploratory nature of the research, the need to integrate mechanical elements with measurement and data acquisition systems, and the goal of clarifying the relationships between design parameters and the device’s functional performance.

The components considered essential for the design of such a device are: the geometry of the punch, the nature of the processed material, the force measurement technology, the methods of data acquisition and recording, the parameters measured during shearing, variable technological factors (e.g., speed, roughness, temperature), the practical applications targeted, the way of clamping the assembly, the type of machine tool used, the structure of the die and the mechanism for generating the cutting movement.

To comprehensively design a system for monitoring the evolution of shear force, each identified component has been explored through multiple configuration options, tailored to specific experimental or practical requirements. These components and their variants are summarized as follows:

*1. Types of punches.* The punching element plays a critical role in the shearing process. Several punch geometries have been considered to analyze their effect on cutting behavior and force magnitude variation:

- Straight-tip punches, typically used for precise vertical cuts;
- Inclined punches, enabling progressive shearing and reduced peak force;
- Curved or profile punches, suited for special contour applications;
- Custom geometry punches, designed for specific research or industrial tasks.

*2. Workpiece materials.* The material subjected to shearing significantly influences the magnitude and pattern of the force. The study covered:

- Carbon and stainless steels, representing common structural materials;
- Aluminum and its alloys, known for their ductility and machinability;
- Technical polymers such as polylactic acid (PA), polycarbonate (PC), and Polyethylene terephthalate glycol (PETG), for lightweight applications;
- Layered composites, to explore force distribution in multi-material systems.

*3. Force measurement systems.* Accurately measuring the force exerted during the shearing operation is essential. Various instruments have been evaluated:

- Mechanical dynamometers, suitable for fundamental measurements;
- Electronic and piezoelectric dynamometers, providing high-resolution data;
- Hydraulic gauges, used for broader force ranges;
- Load cells, integrated with digital interfaces for continuous data logging.

4. *Data acquisition and recording.* To record the measured parameters, several acquisition and monitoring technologies have been analyzed:

- Microcontrollers (e.g., Arduino, STM32) for real-time control and logging;
- Digital oscilloscopes, for waveform analysis of force variation;
- DAQ interfaces with dedicated software, allowing structured storage and analysis;
- Mobile or wireless applications, supporting remote access and cloud integration.

5. *Monitored process parameters.* The experimental setup enables tracking of various indicators relevant to cutting performance:

- Maximum shear force, a key performance metric;
- Force evolution over time, useful for understanding deformation stages;
- Dissipated energy, correlated with material toughness;
- Rate of variation or force slope, indicating process stability.

6. *Controlled variable factors.* Several parameters could be deliberately varied and controlled during testing to evaluate their influence on results:

- Relative motion speed between the punch and die;
- Functional clearance, i.e., the gap between active elements;
- Temperature of the workpiece material, affecting ductility;
- Material surface roughness, influencing friction and crack initiation.

7. *Clamping and driving systems.* The stability and motion of the test setup were ensured using various actuation and fixturing mechanisms:

- Clamping systems, either fixed, adjustable, or guided;
- Press types, including mechanical, hydraulic, and servo-controlled;
- Machine integration, such as adapted lathes and universal testing machines;
- Die types, from simple to compound and progressive configurations.

8. *Shearing mechanism types.* Depending on the application, different motion and force transmission systems have been examined:

- Direct actuation via press ram or tool holder;
- Servo-assisted systems, allowing programmable control;
- Eccentric-driven mechanisms, suited for cyclic or oscillatory shearing.

9. *Application contexts.* The developed configuration supports multiple practical and research objectives:

- Process optimization, by evaluating parameter effects on quality and force;
- Material testing, especially in comparative tests;
- Tool design validation, especially regarding durability under cyclic loads;
- Educational use, offering a didactic platform for demonstration and analysis.

Figure 2 illustrates a simplified version of the idea diagram, built by synthesizing the options and decisions described above. This diagram serves as a conceptual map for selecting, designing, and analyzing a system dedicated to tracking shear force variation in cutting operations.

Following the development of the idea diagram, several component combinations were analyzed. One configuration of particular interest includes the following elements: inclined punch (A2), technical polymer material (B4), electronic dynamometer (C3), data acquisition interface with dedicated software (D1), force evolution tracking over time (E2), punch–die clearance control (F3), use of comparative simulations (G5), precise punch guidance (H2), lathe adapted with a special device (I5), simple die (J3), and a direct shearing mechanism with punch and die (K1). This configuration (A2-B4-C3-D1-E2-F3-G5-H2-I5-J3-K1) was selected to enable the use of the device on a universal lathe for applications beyond conventional turning, effectively adapting it into an experimental platform for shearing process analysis. The chosen combination reflects an optimal balance between feasibility, cost-effectiveness, and educational and experimental value, while allowing for detailed investigation of force behavior during cutting.

The developed mind diagram provided a structured overview of the essential components required for designing a device to monitor force

Fig. 2. The idea diagram developed to identify a solution for tracking the evolution of the shear force magnitude.

variation during shear cutting. It can be concluded that the idea diagram method serves between structural elements, measurement techniques, and key parameters influencing the analyzed technological process.

## 5. PROPOSED SOLUTION FOR A DEVICE TO HIGHLIGHT THE VARIATION OF THE FORCE MAGNITUDE DURING SHEAR CUTTING

The proposed experimental device (Figs. 3, 4, and 5) was developed to enable the study of force variation during the shear cutting process, using standard machine tools and accessible instrumentation. The setup operates by clamping the workpiece within a custom fixture mounted on the lathe’s tailstock, while a movable punch, installed in the tool holder, applies the necessary force to initiate and develop the shearing action. This force is transmitted through a mechanical dynamometer that allows for real-time measurement and recording.

This configuration offers multiple advantages. Firstly, it transforms a conventional universal lathe into a versatile research platform without requiring specialized machinery, thereby significantly reducing the cost of implementation. Secondly, the system provides as an effective tool for conceptual synthesis, enabling the identification of relationships.
direct visualization and recording of the evolution of cutting force magnitude during the process, including key moments such as crack initiation, propagation, and complete separation. In this context, the primary experimental parameter of interest is the maximum shear cutting force, determined as the peak value of the force signal recorded during the process. This parameter can be expressed as:

$$F_{max} = \max(F_t), \tag{3}$$

where $F_t$ represents the time-dependent variation of the force magnitude measured by the data acquisition system. This makes it especially useful for analyzing the mechanics of plastic deformation and optimizing punch–material interactions [11-14].

Additionally, the setup facilitates testing on a wide range of materials and punch geometries, making it an adaptable tool for experimental validation and academic demonstration. The system supports not only qualitative observations but also quantitative analysis of force dynamics, enhancing the educational experience in mechanical engineering laboratories.

However, certain limitations must be considered. The accuracy of the measured force

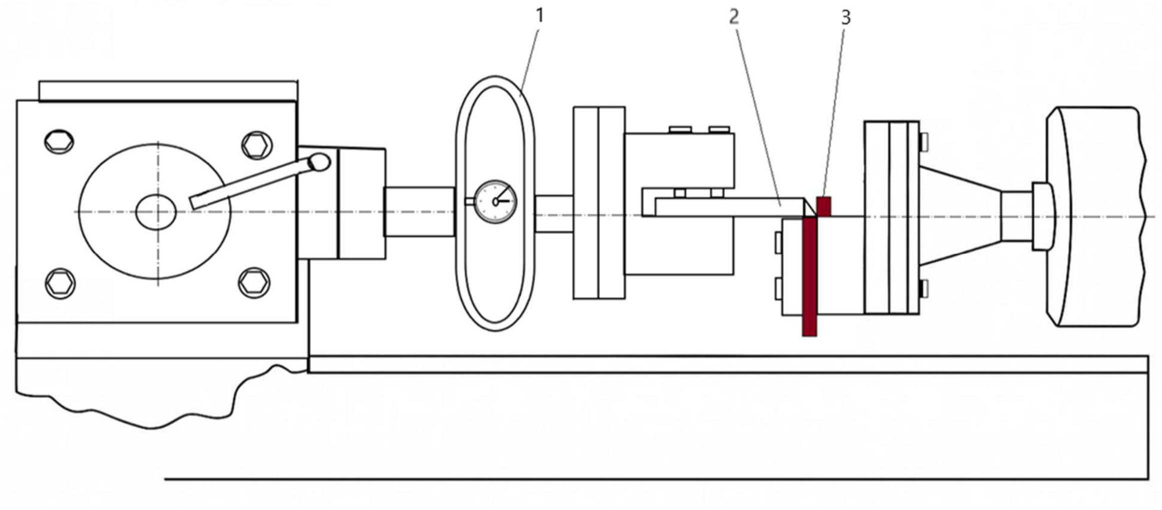

**Fig. 3.** Top view of the device designed to track the evolution of the shear force magnitude: 1 - dynamometer, 2 - punch, 4 – workpiece.

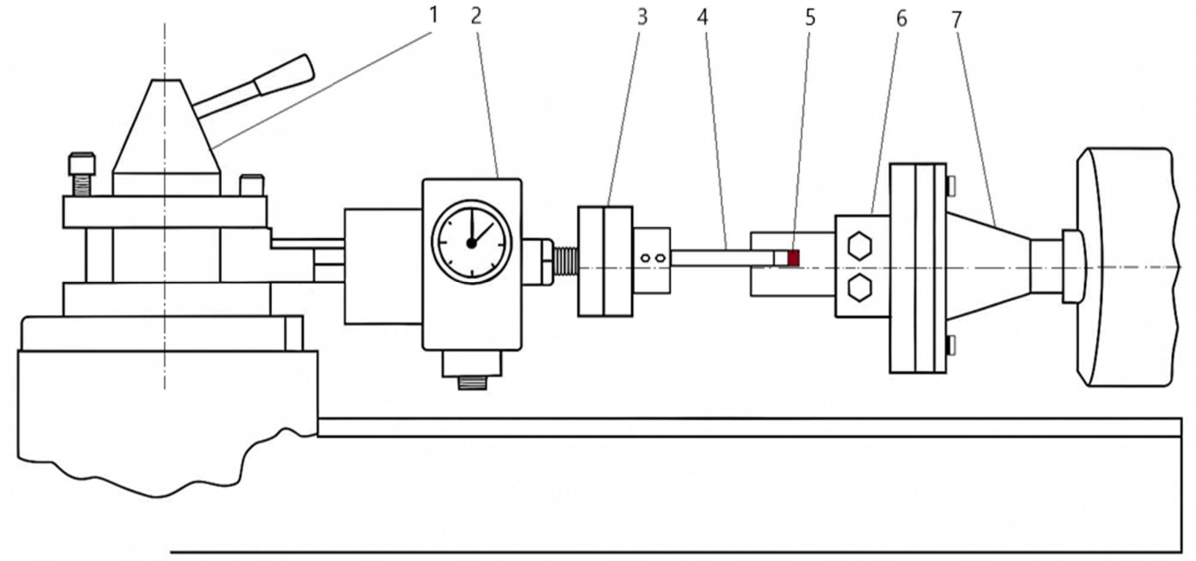

**Fig**. 4. Side view of the device designed to track the evolution of the shear force magnitude: 1- lathe tool holder, 2-dynamometer, 3-punch clamping subsystem, 4-punch, 5-workpiece, 6-workpiece clamping subsystem, 7-moving headstock.

is influenced by the stiffness of the combined lathe–dynamometer assembly. Excessive vibration or backlash may introduce noise into the signal, and the maximum force magnitude that can be applied is constrained by the strength of the components to prevent mechanical failure. Careful calibration and experimental setup are therefore essential.

Despite these challenges, the initial prototype (Fig. 5) was successfully manufactured and tested, proving its functionality and validating the underlying concept. The results of the preliminary experiments confirmed the feasibility of the device and its alignment with the initial design objectives, making it a valuable and accessible solution for shear cutting force analysis.

## 6. CONCLUSIONS

This study addressed the challenge of monitoring the variation in shear force

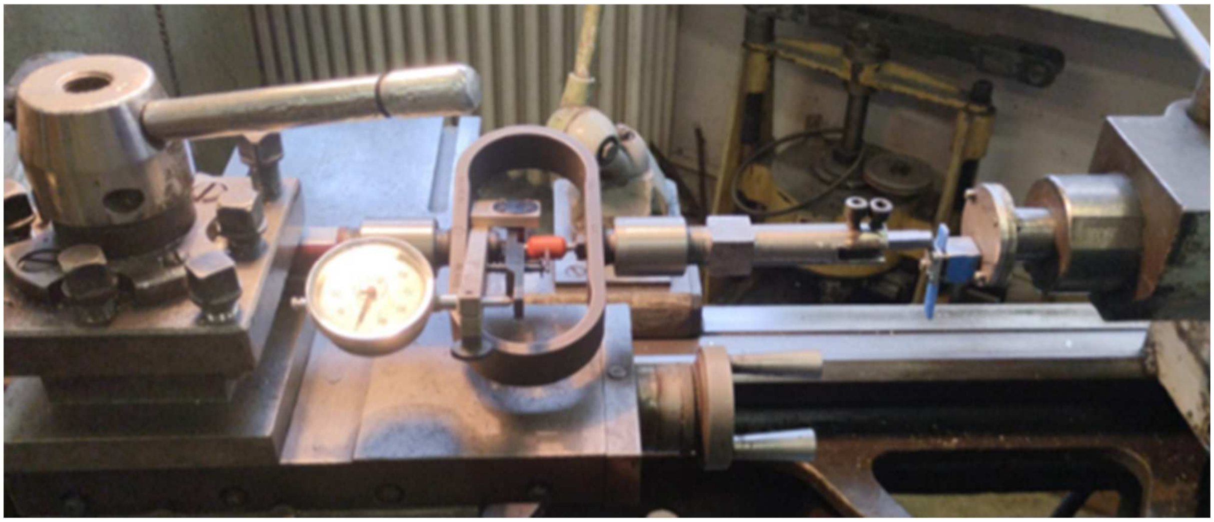

**Fig. 5.** The device intended to track the evolution of the magnitude of the shear force.

magnitude during the shearing process by proposing a device adaptable to a conventional universal lathe. The literature review emphasized the critical importance of accurately determining shear force, not only for the purpose of optimizing technological parameters, but also for ensuring the structural integrity and dimensional precision of the resulting workpieces.

Through the application of analytical models and the integration of mechanical measurement tools, a viable and cost-effective solution was gradually developed. A key contribution of this research is the application of the idea diagram method, which facilitated the logical structuring and conceptual decomposition of the design problem. This method supported a systematic approach that led to the identification of a functional and adaptable configuration using readily available equipment.

The resulting experimental device successfully integrates standard components into an existing lathe platform, enabling both real-time force monitoring and detailed analysis of the shear cutting process. Its versatility allows it to be used not only in research laboratories but also in educational settings, where it can serve as a valuable tool for demonstrating fundamental concepts in material deformation, force measurement, and process analysis.

Moreover, the qualitative nature of the idea diagram method provides a strong conceptual framework for future improvements, encouraging innovative thinking and structured experimentation. Potential directions for further research include the automation of data acquisition and real-time signal processing, the development of predictive models based on empirical data, and the extension of testing capabilities to a broader range of materials, workpiece thicknesses, and tool geometries. Integration of active control systems and digital feedback loops may further increase the accuracy, repeatability, and overall efficiency of the shear cutting process.

In conclusion, the proposed device offers a well-balanced solution in terms of cost, adaptability, and technical relevance, and stands as a promising platform for both experimental investigation and educational demonstration of shear force dynamics.

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## Utilizarea metodei diagramei de idei pentru conceperea unui dispozitiv care să evidențieze variația mărimii forței în timpul tăierii prin forfecare

*Existența unor informații privind comportarea la forfecare a diferitelor materiale este utilă atunci când se urmărește optimizarea condițiilor de tăiere prin forfecare a semifabricatelor din materiale metalice sau plastice. În lucrare, a fost abordată problema conceperii unui dispozitiv care să permită studiul experimental al comportării la forfecare a diferitelor materiale. Pentru a identifica o soluție corespunzătoare a unui astfel de dispozitiv, s-a utilizat o metodă de stimulare a creativității tehnice și anume metoda diagramei de idei. Prin aplicarea principiilor legate de această metodă, a fost conturat treptat un dispozitiv care să permită studiul comportării la forfecare a unor materiale. Dispozitivul poate fi adaptat pe un strung universal și oferă condiții pentru evidențierea influenței exercitate de către diferiți factori asupra variației mărimii forței necesare pentru materializarea unui proces de forfecare.*

**Rica Georgiana BÂZDÂGĂ**, student, Gheorghe Asachi” Technical University of Iași, Department of Machine Manufacturing Technology, Blvd. D. Mangeron, 59A, Iași, 700050, Romania, rica-giorgiana.bazdaga@student.tuiasi.ro, +40787202090.

**Gheorghe NAGÎȚ,** PhD Professor, Eng., “Gheorghe Asachi” Technical University of Iaşi, Department of Machine Manufacturing Technology, Blvd. D. Mangeron, 59A, Iaşi, 700050, Romania, nagit@tcm.tuiasi.ro, +40723936351.

**Alexandra Anamaria SPIRIDON**, student, Gheorghe Asachi” Technical University of Iași, Department of Machine Manufacturing Technology, Blvd. D. Mangeron, 59A, Iași, 700050, Romania, alexandra-anamaria.spiridon@student.tuiasi.ro, +40787690283.

**Marius Andrei MIHALACHE, PhD, Associate Professor,** Eng., “Gheorghe Asachi” Technical University of Iaşi, Department of Machine Manufacturing Technology, Blvd. D. Mangeron, 59A, Iaşi, 700050, Romania, marius-andrei.mihalache@academic.tuiasi.ro, +40 745356715.

**Oana DODUN,** PhD Professor, Eng., “Gheorghe Asachi” Technical University of Iaşi, Department of Machine Manufacturing Technology, Blvd. D. Mangeron, 59A, Iaşi, 700050, Romania, oana.dodun@academic.tuiasi.ro.

**Laurențiu SLĂTINEANU,** PhD Professor, Eng., “Gheorghe Asachi” Technical University of Iași, Department of Machine Manufacturing Technology, Blvd. D. Mangeron, 59A, Iași, 700050, Romania, laurentiu.slatineanu@academic.tuiasi.ro, +40723718675.