

AUTOMATION OF HOT DIE FORGING PROCESSES – ANALYSIS OF TECHNOLOGICAL CHALLENGES AND EXAMPLES OF INDUSTRIAL IMPLEMENTATIONS^{1,2}Lukasz DUDKIEWICZ, ¹Marek HAWRYLUK, ¹Jan MARZEC¹Wroclaw University of Science and Technology, Wroclaw, Poland, EU, lukasz.dudkiewicz@pwr.edu.pl,
marek.hawryluk@pwr.edu.pl, jan.marzec@pwr.edu.pl²Schraner Polska, Leczyca, Poland, EU, ldudkiewicz@schraner.pl<https://doi.org/10.37904/metal.2026.5277>**Abstract**

This paper presents an analysis of the potential for automation of the hot die forging process, considering the types of forging units used and the feed and material handling strategies. The research is based on our own experience and R&D work related to the implementation, design, and testing of robotic cells for the production of die forgings, including high-volume production (≥ 0.5 million forgings per year). The paper focuses on comparing forging presses and hammers, taking into account the number of robots in the forging cell and the method of holding the semi-finished products – both through direct robotic gripping and by leaving the workpiece in the tool cells. The paper emphasizes the important role of FEM simulation software and robot trajectories in the design and optimization of robotic forging processes. The most typical cell configurations are presented, including two-robot systems used on presses and hammers. It has been demonstrated that forging presses favor the use of multi-robot systems (two robots per forging line) without holding the workpiece, which enables the simultaneous execution of several operations and increases automation efficiency. Hammer automation, on the other hand, requires limiting the number of robots (1-2) and adapting the gripping strategy to the dynamic nature of the process, which impacts the design of the cells and the sequence of operations. Effective automation of forging processes depends on the optimal selection of machine type, number of robots, and method of batch manipulation during the forging production process.

Keywords: Precision forging, hammers and presses, forging automation, robotic forging**1. INTRODUCTION**

The use of forging is currently very challenging. Rising energy prices, as well as the cost of direct and indirect materials for production, require human intervention when damage occurs during large production runs, and, on the other hand, the need to operate forging units. Harsh working conditions, including dust, electric fields, and high temperatures within reach, are not factors in ensuring access to the site for younger generations [1]. Forges are considering the implementation of automation and robotization of key work areas to reduce employee workload, remove them from sources of electromagnetic fields, and shift their role from operator to process supervisor [2]-[4].

Automation and robotization allow for the utilization of production efficiency, stabilizing processes and limiting the impact of human input on production quality. An additional advantage, which includes the importance of hot forging, is the prestige resulting from the increased technological level, which translates into increased interest from forging customers, primarily from the automotive industry.

The main driver for seeking automation solutions was the limitation of human capabilities, primarily resulting from physical limitations in the scope of work performed. Automation of manufacturing processes dates back to the 1940s. The concept of robots supporting physical work was developed in the 1950. **Table 1** summarizes

the most important achievements of key importance for robotization from the 2000 to 2025, with particular emphasis on applications in hot die forging processes worldwide [2].

Table 1 Progress in robotization process, especially regarding the hot-drop forging process [2],[3]

Year	Implementation	Location
2004	Development of a synchronization system of 4 robots	Japan
2006	Development of the first robot cooperating with the human	Germany
2008	Development of a robot with the weighing capacity 1200 kg	Japan
2009	Development of a synchronization system of 8 robots	Japan
2010	Introduction of robots for hot rolling of materials	Germany
2011	The first robot (humanoid) sent to space	USA
2013	Introduction of proximity robots (corobots) into the market	USA
2014	Introduction of support robots during forging on a hammer	Germany
2016	Implementation of the gripper during hot rolling	Germany
2017	Introduction of SCARA-type robots	Japan
2018	Introduction of automatic forging process on a hammer	Germany
2020	Introduction of KR Delta-type hygienic robots	Germany
2020	Implementation of the gripper during hot rolling	Poland
2021	Implementation of robot during deburring process	Poland
2022	Introduction of robots during forging on a press	Poland
2025	Introduction of robots during forging on a hammer and deburring process	Poland

As can be seen, there are many examples of successful implementation of automation in packaging, welding, product handling, and mechanical processing, which are simple processes. However, in the case of heavy industry, including die forging, robotization poses a significant technical and technological challenge [5]. It is undoubtedly true that introducing automation and robotization to forging processes is disproportionately more difficult than introducing it to other manufacturing processes, compared to welding, assembly, or stamping. It should be emphasized that there are many more robotic processes in die forging on presses than on hammers. Hammers [6] are much faster than presses [7] (approx. 10 times faster), generate significantly higher vibrations (approx. 5 times the vibration and acceleration frequency [7]) and tool assembly deflections, and also require a different approach to forging tool design (greater forging inclinations on the hammer compared to presses [8]), which significantly complicates automation [2].

The aim of the work is to analyze the technological challenges during the automation and robotization of the hot die forging process on presses and hammers and to present the effective implementation of press and hammer forging in industrial conditions in order to ensure repeatability and stability of production, as well as to relieve the operator-blacksmith from working in a difficult work environment.

2. MAIN AREAS TO BE ANALYZED WHEN INTRODUCING AUTOMATED FORGING PROCESSES

Implementing an automated and robotic hot die forging station [9] requires switching from the manual [10] process to the robotic mode. To achieve this, the manual process must be stable and repeatable. Information obtained by the authors of this paper [12]-[14] indicates that robotization and automation make practical sense when the demand for a single product is at least 0.5 million pieces per year. However, in the face of an order crunch, large series, for which robotization makes the most sense, are being abandoned, which undermines its profitability and requires a new approach to the design of automated lines. Therefore, for the effective

implementation of automation, it is crucial to properly understand the process and its execution, as well as engage experts from various technical fields to address such a complex issue. According to the authors, the key areas that need to be analyzed during the implementation of an automated hot die forging process are [1],[2],[9]:

- Comprehensive analysis of manual technology, including identification of key issues and potential automation opportunities;
- Strategy for implementing the forging process (material held or unheld during operation);
- Selection of the appropriate number and design of robots for industrial applications;
- Application of numerical modeling and offline simulation tools to select robot trajectories, synchronize operations, and verify line operation (including collision and cycle time analysis);
- Stable and repeatable feedstock temperature at the heater outlet;
- The need to develop new forging tool designs for the automated process;
- Development of grippers enabling the picking/gripping and manipulation of feedstock and semi-finished products, which must be resistant to high temperatures;
- Methods for maintaining a stable temperature of forging tools and applying lubricant;
- Software integrating all line components for correct, efficient, and synchronized operation [1],[2],[9].

3. SIMULATION TOOLS AND DESIGN IN ROBOTIC DIE FORGING

Implementing robots in hot forging processes requires selecting industrial robots with appropriate payload capacity, reach, and speed, capable of operating in high-temperature, dusty, and vibration-prone environments, such as Fanuc Harsh Environment or KUKA Foundry Plus systems. Modern approaches utilize simulation software (e.g., ABB RobotStudio, Fanuc RoboGuide) to enable virtual analysis of robot motion trajectories and their initial optimization (**Figure 1**).

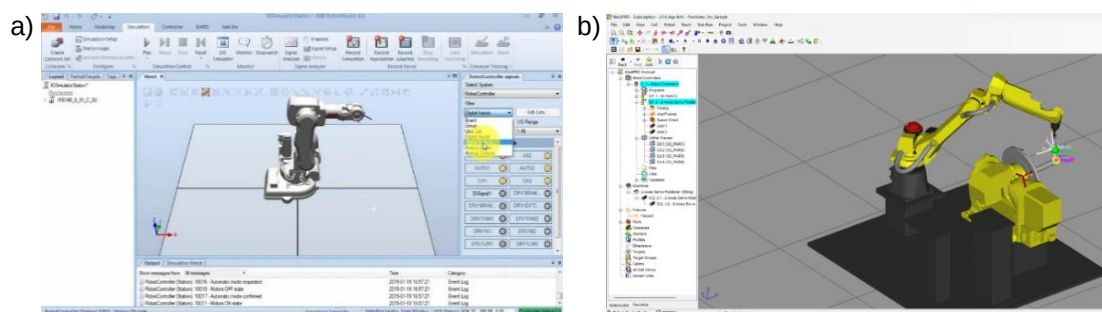


Figure 1 Interface views from preliminary robot simulation setups and parameter configurations in: a) ABB RobotStudio [15], b) Fanuc RoboGuide software environments [16]

Simultaneously, numerical simulations of the forging process, including material deformation and forming, are conducted in dedicated computational packages, enabling the integration of the technological model of the process with the design and optimization of robotic systems. The authors' exemplary research on the robotization of a forging line [16] on a press first included numerical modeling of the forging process in Forge software (**Figure 2a**), followed by implementation of the obtained results in the ABB RobotStudio environment. This enabled research to be conducted in a virtual environment, analyzing robot motion trajectories, eliminating potential collisions, and selecting optimal design and technological solutions (**Figure 2b**). To validate the virtual models, optimize robot trajectories, and integrate them with the press assembly, industrial tests were conducted to verify the model assumptions and fine-tune the system parameters (**Figure 2c**).



Figure 2 View: a) Final simulation results analysed forging process - distribution grains size, b) press forging line, c) photographs from the first industrial trials and system commissioning [2]

Ultimately, a three-robot system was used: two for collecting material from the heater and forging, while the third was responsible for receiving the forging and transferring it to the trimming operation. This constituted the optimal technical and technological solution for the analyzed process. Initial commissioning and industrial trials (**Figure 2b**) confirmed the correctness of the adopted assumptions and the high reliability of the integrated robotic system, confirming the effectiveness of the simulation-based approach. However, it should be emphasized that the automation of forging processes requires an individual approach to each technological case.

4. CLASSIFICATIONS OF AUTOMATED FORGING PROCESS ON PRESSES AND HAMMERS

The authors presented various approaches to the automation and robotization of the hot die forging process for the most commonly used forging units, such as presses and hammers, as shown in **Figure 3**.

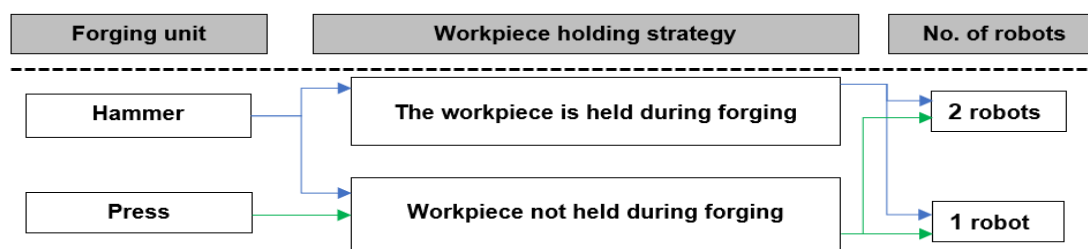


Figure 3 Classification of automation of forging presses and hammers (own study)

The first division is the type of forging unit used: hammer and press, which differ significantly in their operating characteristics. Next, a choice is made regarding the strategy for holding the workpiece during the forging process. In the case of presses, the feedstock is not held during the forging unit's operation. In the case of hammers, two approaches are used: the feedstock is held or not held during the forging process. Holding the feedstock during forging is used when producing forgings in multiple systems with a single forging weighing up to 1 kg, where the feedstock is relatively long (over 300 mm). Forgings weighing over 3 kg are mainly forged in single systems, which does not require holding the semi-finished products during forging. The final stage is the number of robots involved in the forging process itself. When using a single robot, the implementation cost is relatively low, but the cycle time and process efficiency are also low. When a high-performance process is required, two forging robots are often used for the forging itself. However, each of the presented approaches to forging process automation has its advantages and disadvantages.

5. HOT DIE FORGING WITH A HAMMER – EXAMPLE OF A SOLUTION

A solution for an automated hot die forging process using a hammer was presented by Lasco Umformtechnik GmbH [11][18]. They developed a concept in which two robots hold the input material while a hydraulic hammer is striking. **Figure 4a** shows a process simulation, while **Figure 4b** shows a view of the process implemented according to the assumptions.

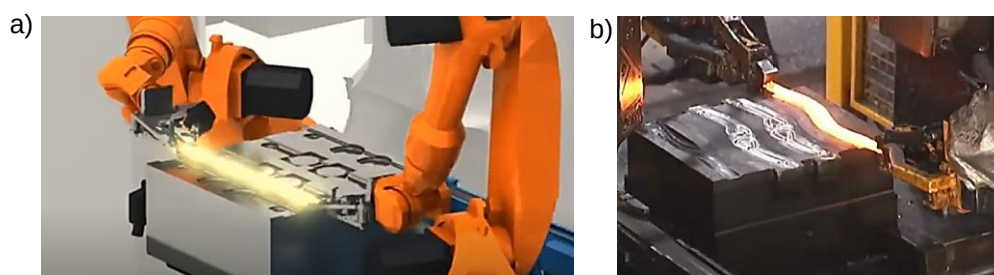


Figure 4 The forging process is carried out on a hammer with continuous holding of the charge material during the impact: a) conceptual diagram, b) view of the implementation of the automated forging process [11],[18]

After heating it to forging temperature, the charge material is collected from both ends using two robots (**Figure 4b**). It is formed on the bending station and transferred to the pre-die die station, where the forging unit strikes while the robots hold the charge at both ends. It is then transported to the finishing station, where another strike from the forging unit occurs.

Robotic forging hammers is very challenging due to the dynamics of the process itself (forming time: 0.05 s), high mechanical vibrations (acceleration in the direction of the ram movement: 1.5 m/s^2), dust, and high temperatures. Due to the dynamics of the process, the grippers and robots are exposed to the influence of the process dynamics on their proper functioning, which requires the development of an effective material and design solution. The strategy of implementing the hot die forging process on a hammer using two robots holding the feedstock is characterized by the most stable and repeatable process, while ensuring a very short cycle time (5-8 seconds). The significantly higher implementation cost is undoubtedly the most popular solution for implementing hammer robotics in forges, ensuring high process efficiency.

6. HOT DIE FORGING ON A PRESS – EXAMPLE OF A SOLUTION

In the case of screw, friction screw, and crank presses, solutions involving the use of two robots are also used, i.e., on the left and right sides of the press (viewed from the front of the press) **Chyba! Nenalezen zdroj odkazů..** One manipulator is responsible for loading the hot charge material and transferring it from cell A to cell B, while the second manipulator is responsible for transferring the forging from cell B to cell C, and from cell C out of the machining zone, as shown in **Figure 5**. This solution is characterized by a very short cycle time (several seconds), but a correspondingly higher implementation cost and the advanced nature and number of necessary forging tools. This solution is predisposed and most frequently observed in implementations for the production of axisymmetric forgings. Forgings cannot be produced in multiple configurations to increase forging efficiency. The components are mainly forged in a single-pass configuration.

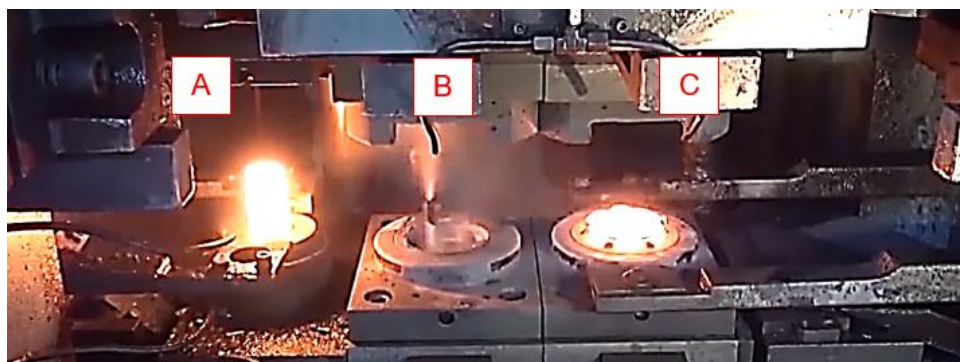


Figure 5 The forging process is carried out on a screw-friction press **Chyba! Nenalezen zdroj odkazů.**

Robotization of forging presses is easier than robotization of hammers and is much more commonly used in industrial processes. This is due to the dynamics of the process itself, which is 10 times slower on presses than on hammers (forming time 0.5 s), three times lower mechanical vibrations (vibration acceleration in the direction of ram movement 0.5 m/s²), and the fact that such solutions are supplied directly by press manufacturers along with the forging units themselves. Due to the shape of the parts themselves (primarily axisymmetric forgings), the design of grippers is significantly simpler compared to hammers.

7. CONCLUSION

It has been demonstrated that forging presses favor the use of multi-robot systems (two robots per forging process), which enables the simultaneous execution of several operations and increases automation efficiency. The main areas for analysis during the effective implementation of automated hot die forging are presented, and it is emphasized that to transition from manual to robotic, the manual process itself must be stable and repeatable. Hammer automation requires limiting the number of robots (1-2) and adapting the gripping strategy to the dynamic nature of the process, which affects the design of the nests and the sequence of operations. Effective hammer automation enables high process efficiency, and the cycle time using two robots is 5-8 s [18]. Screw press automation **Chyba! Nenalezen zdroj odkazů.** is characterized by greater versatility and flexibility and is dedicated to the production of axisymmetric products. The analysis revealed that large production runs are currently being abandoned due to the order crunch and the growing importance of flexibility and adaptability to smaller batches of several thousand forgings. The analysis revealed that effective automation of forging processes depends on the optimal selection of machine type, number of robots, and method of handling the semi-finished products. Currently, in the case of automation, a number of IT support tools are used, such as programs for numerical modeling of forging or for simulating the trajectory of robot movements, which confirms that even forging processes that are difficult to robotize are covered by the ideology of Industry 4.0.

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