IDENTIFICATION AND ANALYSIS OF DEFECT IN FORGING TOOLS BY NON-DESTRUCTIVE DETECTION METHOD

Abstract
The forging tool has its irreplaceable location across a wide range of industrial production including automotive, aviation and bearing industry. The use of forging tools in serial production has led to a huge increase in consumption of forging tools. By following the productivity and economic benefits of using the tools, the need for rapid and flexible tool renovation is also growing. It is primarily based on the reliable identification and analysis of cracks occurring during operation. This article deals with the application of non-destructive detection technology in assessing the size of the defects of forging that arise in the molding process.

Keywords
forging tools, renovation, non-destructive detection technology

1 INTRODUCTION
Forging is one of the most economical manufacturing methods for making parts out of steel and non-ferrous metals. Advantages of forging in comparison to other methods include significant savings in materials, higher production rate, better grain structure and better surface quality. Requirements for construction materials for forging tools must comply with the high demands of the mechanical, physical and chemical aspects of high strength, toughness and hardness. Technical and technological processes depend on these characteristics, which directly affects the cost of the individual components and their competitiveness. Following impact, the tools have a longer shelf life, thus there is less downtime needed for replacement and repair. In this way, we can make better use of production machinery and equipment. Tools made of special hardened materials are highly cost-intensive, and therefore their design already considers the possibility of manufacture, renovation or repair. Generally, when machining materials with impaired machinability and high hardness, non-cutting technologies that achieve high productivity, flexibility and excellent functional properties are used. The biggest problem is to choose the right technology, which will restore the original mechanical and physical properties of tools or instruments as soon as possible at a competitive price.

Temperature fluctuations on the surfaces of forging tools, plastic deformation, and the influence of thermo-mechanical stress lead to alternating thermal fatigue and cause surface cracks. These defects significantly affect the quality of finished forgings and the lifespan of the forging die itself. To capture and track these defects, several destructive and non-destructive methods can be used for the detection of cracks within the tools. For fixing forging dies, non-destructive methods that do not disturb the shape and surface components are desirable.

2 PRINCIPLES OF FORGING
Die forging is used for mass production (Fig. 1). The principle is that the heated material takes the final shape of the die cavity with one or more stroke. This method gives a more accurate shape compared to free forging. The accuracy of the surface can be significantly improved by further finishing operations such as calibration and a quality surface can be achieved, which should not be further cultivated. Using die forging, a high degree of reduction of material and fibres is achieved, which has a positive effect on the mechanical properties of the material [1].

![Figure 1. The principle of die forging](image)

To start, a blank is inserted into the lower part of the opened die. By action energy shaping, the machine moves one part of the die against another while the starting material fills the cavity. By fully grasping the die cavity, it is filled and transformed into the desired shape. The procedure for filling a cavity influences the speed of deformation, which depends on the type of machine. The impact of hammers causes greater speed creep in the direction of shock and the force of the press still makes better filling of cavities in a direction perpendicular to the acting force. These differences in filling the die cavity influence the choice of the type of molding machines and forging operations for the part [2].
Blacksmith tools manufactured from special tool steel tool are highly cost intensive. The main part of the cost is attributable to the material itself, heat treatment and other chemical-thermal treatment of the surface. Therefore, the possibility of renovation or repair is already considered in the actual design of the die structure. An important aspect of the renovation process itself is the right choice of technology to restore the power tool's original mechanical and physical properties, of course at a competitive price. The main challenge in selecting appropriate technology for tool renovation is heat treatment of high hardness and die surface treated by nitrided layer, which increases the resistance of the die cavity to scratching. In particular, the forging process leads to mechanical stresses that cause wear on the shape of the die (Fig. 2) and also fatigue fracture, which reduces the quality of finished forgings. Therefore, after a fixed life, a die forging is removed from the forging process and sent for repair or renovation.

![Figure 2. Wear of die forging](image)

Cracks can occur as a result of using the wrong terms of production. A poor cooling process for cast or forged parts, overheating during the grinding, or excessive tension during the manufacturing process are common causes of cracks. Cracks are defined as a narrow gap where the length along the surface is at least ten times greater than the depth in the material, and a visual example of cracks on a forging tool is shown in Fig. 3. In addition, the width of the fracture is very small, at least ten times smaller than the depth. The bottom of the fracture is mostly sharp, causing sharp notches in the material. Due to mechanical stress, especially when changing or alternating loads, there is a sharp notch at the bottom of the tension that can cause enlargement of cracks [3].

It is therefore very important to always pay close attention to cracks. Early detection and assessment of cracks are very important. This is especially true for surface cracks. In most cases exposed parts such as auto parts are subjected to the biggest stress on the surface. It is also important to note that not every flaw can damage components. The rule of crack mechanics says that some cracks can be tolerated. This depends on many factors and sometimes it is difficult to decide whether to use standard methods or nondestructive material testing [4,7].

Renovating is a special case of repair, where the repaired object is a machine component. It is a work of restoring their functional properties to damaged machine parts. Renovation is a set of activities carried out in order to restore the operational status of components and extend their lifespan. It is a separation in which worn parts are restored to their original geometric shape, size, and functional and mechanical properties in accordance with drawings and technical specifications. Renovation may be seen as a repair sub-sector, which contributes to reducing the cost of restoration and operation of machinery, but it can also be seen as a special case of recycling materials, which, moreover, reduces the demand for raw materials and energy sources [4].

Before renovation, it is necessary to map the extent of tool wear and infer the extent of renovations and technology needed. Range is determined by the size of the fracture surface that is removed by machining such that the outer surfaces show no signs of defects. This process is usually performed by visual observation using surface optical devices that can find the largest size defects generated in the forging process, which prevent efficient use. As control is exercised by subjective workers who often cannot assess the degree of wear, not least the size of the fracture, the process is repeated until all defects are removed. It often happens that the extent of wear is destructive for the die, which is able to detect only a few controls and subsequent surface treatment. From an economic point of view, the time and cost to renovate increases. Sometimes it is necessary to completely remove the forging dies during the renovation process due to excessive wear and damage. This process is well run and used in practice and seeks to simplify and intensify the technology of renovations.

![Figure 3. Surface fatigue cracks on the functional surface of die](image)

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![Figure 4. Examination of cracks by nondestructive technology with Crack Depth Meter RMG 4015](image)

For this purpose, various methods are used to survey defects in materials and products, whether they are destructive or nondestructive detection technologies that can assess the extent of wear and thus offer more
renovation options. Defectoscopy is a nondestructive method, and it is one of the best choices for renovation due to its ability to change the status of the sample for future use (Fig. 4).

3 CRACKS DETECTION

Ultrasonic testing arose from the need to identify hidden internal defects in components that could lead to accidents involving finished products. It is a nondestructive testing method and has considerable importance in improving quality and reliability in industry, especially in engineering. It is one of the most important methods of nondestructive testing of materials and can detect material discontinuities resulting from the production process as well as from mechanical stress during operation [5,8].

The effect of defects on the strength of the material depends on its nature, size and shape, which determine the nature of spatial defects. Planar defects include cracks, cold joints, unattaching and duality, while spatial character defects include bubbles, cavities and pores and are usually less dangerous for the strength of the material. Outside of these defects, whose nature is to be determined, there is also a transition formed between major groups, such as rows of pores and hair pores. The option to specify the nature of the defect depends on the shape of the object and the presence of a surface to which it is possible to attach the appropriate type of ultrasound probe. Detection of the nature or orientation of the defect is based on the directivity of ultrasonic transmission. The reflective property of these components, and thus the shape of the echo, depends on the nature and size of the defect [6,9].

The defectoscopic machine STARMANS ULTRASONIC FLAW DETEKTOR DiO - 562 - reflective device is used for the detection of defects in the tested material and is equipped with a universal probe for measuring flat surfaces.

Figure 5. Measurement of dies measured die, measured crack, ultrasonic probe and measurement of dies: front die, measured crack on volume, measurement from the bottom of the die, and the principle of crack depth detection by ultrasonic method

The Measuring systems use three methods and that measuring probes, die-limited options, and cavity shape measurement (Fig. 5). Crack measurements can be from three directions, namely from the face, the outer periphery, and the bottom of the die. The basic measurement is focused on the forging die head (Fig. 6), but this does not give the desired results, because in this way it is not possible to capture the crack. This is justification for the diversity of internal die profile and a type of probe that has not been adapted for this measurement procedure.

Figure 6. Start measuring the forehead and around the perimeter dies

As a result, measurement is focused on the method of measuring the outer perimeter of the die. The die profile with rounded internal diameter by producing turning (Fig. 7, left), and it is not possible to measure the outer circumference or any significant and relevant dimension of the crack. Only cracks with forged internal profile produced by milling can be detected, as shown in Fig. 7 on the right. Detail of cracks and record measurements are shown in Fig. 8.

Ultrasonic flaw detection apparatus EPOCH LT a EPOCH 600, on the sample, there were several cracks that could be visually detected and the intention was to measure their size using this device. Unfortunately, even this method has not conclusively determined whether there was a crack or whether there is an error. This is one of the main reasons we consider the complex and rugged profile of the crack, which caused consistent contact with the surface probes of die. For this reason, and following dialogue, it was decided to repeat the measurement with the device EPOCH 600th. This device unfortunately yielded equally unreliable results as its predecessor EPOCH LT and measurement has been completed.

Figure 7. Start measuring the forehead and around the perimeter dies
4 EXPERIMENTAL MEASUREMENTS

Determination of depth and orientation of surface cracks our new crack depth gauge RMG 4015 measures crack depths on workpieces of iron, ferrous and austenitic steels and can also be used for cracks in copper, brass, aluminium and other non-ferrous metals. For the measurement of oblique cracks a special oblique cracks probe is available. The crack depth measurement device RMG 4015 was used to detect the depth of the cracks.

A probe with four spring-loaded and gilded contact pins is positioned across the crack to be measured on the workpiece. A constant alternating current is passed via two of the pins into the workpiece; the two other pins measure the voltage drop across the crack, where the crack depth is derived from. The a.c. of the instrument utilizes the skin effect, which forces the current flow to the surface of the conductor and therefore follows the contour of the crack. The operation and measured value formation are monitored by the microprocessor of the gauge. Incorrect handling or faulty measurements caused by wrong attachment or imperfect contacts therefore are out of question.

Crack depth determination with the potential probe method is based on the measurement of the electrical resistance between two points on the surface of a metallic workpiece. If there is a crack between these two points, the electrical resistance is higher than for a crack-free surface. The resistance will grow with the unknown crack depth. In this new approach, a four-pole technique is used fig. 9.

![Figure 9. Sample on the measuring table of x-ray diffractometer](image)

Two current poles S1 and S2 enforce a constant current through the workpiece. The voltage U is measured between the other two measurement poles M1 and M2 and it is proportional to the electrical resistance between them. Therefore, the voltage U depends, in a characteristic manner, upon the unknown crack depth h, the known distances of the measurement poles 2a and the current poles 2s, and the electrical and magnetic properties of the material.

In case of alternating current (AC), the skin-effect shifts the electrical field and the current lines towards regions just below the surface. Also, the current density is increased. The following formula gives the penetration depth in terms of the frequency and the material properties. The higher the frequency, the more severe is this effect, i.e., the current will flow along the crack faces. As for a wire with reduced cross-section, an increase of the resistance is observed. For direct current (DC), no skin effect occurs and the current follows the path of lowest resistance, which corresponds to the shortest geometrical distance.

For a precise crack depth determination with low measuring currents, AC has to be used. Low currents will avoid burnt contact spots to protect the surface of the workpiece and the current poles. Furthermore, the power consumption in case of battery operation will be drastically reduced. Because the skin effect increases the voltage drop across the crack, the effective current path between the poles can be reduced with respect to conventional instruments. Smaller, more practicable probes can therefore be used and provide high resolution and accuracy. Even materials with high electrical conductivity, e.g., high-grade steels or Aluminium, can now be measured.

As seen in the graph of 7. cracks (Figs. 10, 11), the crack spreads from the internal functional area across the top blacksmith dies up to the edge. From the measured values of the crack depth can be read that the maximum depth of the crack is located at the edge of the die. The course of the cracks is significantly different from the other measured cracks, which are much shorter and are found mainly in the vicinity of the internal curvature of the die cavity. This crack has a particular risk, because the next time the die is used there could be further spread and deepening of the cracks, which could lead to the exclusion of the forging die and inability to carry out further renovations.

![Figure 10. Detail of cracks 3, 4 and 5 on die 1. course of 3 and 4. Crack in die 1](image)
In 7. crack the top five crack depth measurements were carried out at the top of the forging die, therefore the depth of measurement has the value 0. The measurement was carried out towards the edge of the external die to the die cavity inner edge.

From the graphic course (Fig. 12) it can be seen that the crack depth increases to a maximum and then begins to fall. It is also possible to see that on the die there are cracks of different depths. Measuring cracks using the RMG 4015 device was quick and smooth, making it possible to demonstrate the practical use of the machine in engineering practice.

5 CONCLUSION

To analyse material errors and cracks by a non-destructive method was used a potentiometric method. Potentiometric method is the preferred method of detecting ultrasonic cracks for crack depth examination. It clearly achieves results faster and is more intuitive for inexperienced workers. The selected portable RMG 4015 was proven to measure the depth of external cracks in all types of matrix regardless of the complexity of the shape or profile. Small errors recorded during the experiments were caused by a non-conducting surface layer that prevented measurement and the type of sensor used was RMSQ 90°. Due to the complexity of the surface and inside the cavity of some matrices that interfere with the tears from the surface of the matrix after the probe, RMSL is proposed. The individual cracks in the matrices were measured and processed graphically. All outputs were subsequently visualized using a CAD system where cracks in the embossing process are visible.

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