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ENHANCED OF TOOL MANAGEMENT BASED ON MACHINE VISION IN THE FIELD OF METAL FORMING TECHNOLOGY

In this article, the authors focused on the widely used aluminium extrusion technology, where the die quality and durability are the essential factors. In this study, detailed solutions in the three-key area have been presented. First is applying marking technology, where a laser technique was proposed as a consistent light source of high power in a selected, narrow spectral range. In the second, an automated and reliable identification method of alphanumeric characters was investigated using an advanced machine vision system and digital image processing adopted to the industrial conditions. Third, a proposed concept of online tool management was introduced as an efficient process for properly planning the production process, cost estimation and risk assessment. In this research, the authors pay attention to the designed vision system's speed, reliability, and mobility. This leads to the practical, industrial application of the proposed solutions, where the influence of external factors is not negligible.

Keywords: die; aluminium extrusion; tool management; machine vision; digital image processing

1. Introduction

Aluminium extrusion, a process in which materials are forced to flow through a narrow opening in a die to obtain a specific profile, has been commonly used for years worldwide [1]. Due to the ever-increasing use of this technology in architecture, construction, aerospace, automotive, transportation and manufacturing industries, many practical and numerical innovations regarding the extrusion die have been developed [2,3]. The extrusion process is carried out through the application of various forms of metal forming technology. The most commonly applied method consists of heating aluminium ingots of a particular geometry and forming the desired profiles by pressing the bars through special, dedicated dies (Fig. 1).

A review of several works dealing with the extrusion process indicates that the most essential business-related factors regarding the production of aluminium profiles is the efficiency of the extrusion process and the price and quality of finished products. All three aspects are closely related to the accuracy of the preparation of the extrusion dies, where the profile value strongly depends on the die quality [4]. Since various tools produce different profiles, the choice depends on the type of manufactured profiles (open or closed). Sometimes the procedure of die selection for a particular profile shape is even more

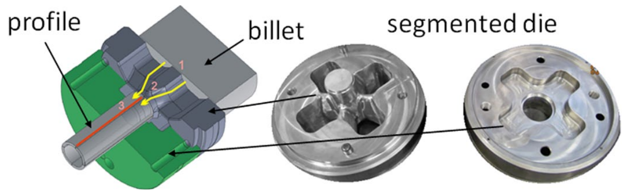

Fig. 1. An example of die design for a regular tube profile extrusion (Extral), includes scheme of the extrusion process and segmented die before assembly

complicated. It is not uncommon that dies delivered by various suppliers differ in design but can be applied to obtain the same profile shape. Such a situation causes that in production plants where knowledge and experience enable the production of a wide range of profiles, hundreds or even thousands of dies may be used. Identifying them by data acquisition collection process is crucial aspect (such as the history of use, repair, adjustment, etc.), for the production company.

The marking of extrusion dies mainly aims facilitate their identification during acquisition from or delivery to the warehouse. Therefore, the primary task of using the data acquisition procedure is to determine the tool wear rate. In the case of dies, the wearing process is associated with a decrease in the dimensional accuracy and some die failure issues of the product, and

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in an extreme case, the incorrect final product production [5-7]. Using the proposed solution based on tool data acquisition, tool wear monitoring is possible based on time, locations, and tasks carried out by the tool. Maintaining a high production quality often depends on the quick replacement of the used equipment at the work stand. The elimination of tool flaws and downtimes is very costly, so an efficient and rapid solution to identify tools markings needs to be proposed. Therefore, attention was ultimately paid to continuously collecting information (acquisition of measurement data) in four primary production areas: tool status, wear rate, production volume, and production quality. Data acquisition can be applied to many aspects of dies in the aluminium extrusion process. These include data recording method, its quality, transfer speed, the registration system's reliability and the information's completeness. The fundamental issue thus becomes the determination of a method for the identification, legibility and durability of applied markings.

In addition, the proposed solution also provides for other possible problems related to the difficulty of identifying markers failure due to inadequate protection. Numerous attempts are made to solve this problem, the most common of which is to propose the synthesis of different sources (independently measured techniques). This results in a flawed concept that may integrate the needs resulting from inadequate protection, pollution, and other factors in complex production. Such an example is the algorithms of support vector machine and Dempster-Shafer theory. This method combines results from different measured techniques and comes to a certain degree of confidence in terms of probability [8]. Unfortunately, this solution requires a fusion of multi-information, which is expensive and not practical in an industrial environment. Therefore, in response to the expectations, the authors first proposed that alphanumeric characters are subject to automatic identification using an optical character recognition process known as OCR. Next, the OCR technique has been completed by digital image processing taking into account damage or inappropriate location of the markers. The advantage of this solution is that the identification marks can be recognized in case of computer system failure or low image quality.

2. Theory

2.1. Tool management

In recent years, a discussion on the possibility of establishing monitoring systems for collecting data about the manufacturing process has contributed to improving existing marking techniques. One of these solutions is a system that applies markings using a laser.

The issue of accurate character recognition is connected to the need to supervise tool data management and proper allocation of its resources [9]. Machine and automotive industries, where there are a significant number of metal forming operations, require a continuous supervision of the transferring tools, as well as their condition due to considerable aspects of planning and predicting the production capabilities of specific product groups. The logistics of this data management process is a decisive factor in production costs. Therefore, it required the proposal of a simple, yet reliable solution that would allow for the definition of the physical condition and location of dies at any point of industrial space, which can be achieved with machine vision based identification and tracking technique [10].

The proposed vision system for the identification of alphanumeric marks, data registrations and a laser marking method are innovations that highlight productive business management by controlling the state of equipment, determining die storage locations, planning the regeneration process and die working load process for metal forming. Fig. 2 shows a schematic of a typical industrial plant, where subsequent storage locations of dies in the production cycle are marked. The beginning of this path in any industrial space is the transport and storage warehouse of the supply of new tools. During the selection process, the specific tool is moved to the proper storing place in anticipation of processing tasks. Prior to the commencement of manufacturing processes, tools are placed in areas specifically designated for installation in the machine. In turn, worn out tools are directed to reintroduction (regeneration). They are moved subsequently to places where specific procedures are performed, e.g. heat treatment or machining.

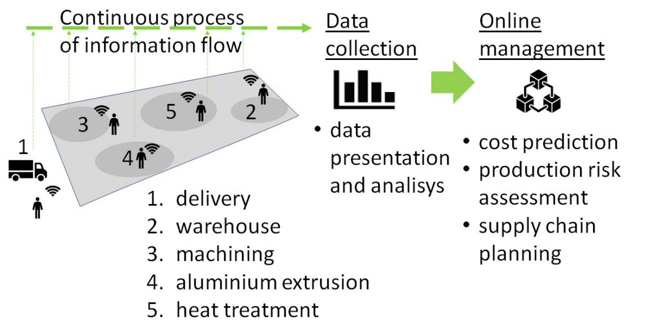

Fig. 2. Schematics of a typical industrial plant with an online management concept

Therefore, taking into account such information as the impact of production factors on the supply chain management [11] or the model of the industrial network of information flow [12], a new logistics solution was developed by the authors, where it is clearly shown that a data acquisition process is essential in each of the storing zones (Fig. 2). It significantly facilitates the process of management and planning, which consists of determining the longevity of tools, operating costs, regeneration costs or the spatial planning of various production departments. Next, the authors' concept of online tool management (Fig. 2) is a significant factor in the proper planning of the production process, cost estimation and risk assessment. It is beneficial in cases with many tools (ranging from several hundred to several thousand in larger industrial plants). Finally, it becomes possible to forecast final costs or evaluate production risk, which can be regarded as part of the contemporary concept known commonly as "Smart Factory", one of "Industry 4.0" principles

2.2. Data acquisition

A significant obstacle in the implementation of automated processes of data acquisition are various issues regarding the exploitation of dies. Systems currently used, such as identification chips with RFID data transmission or PLCs (i.e. programmable logic controllers) [13-14] are facing problems that significantly reduce the chance of reliability of these systems, even based on the most popular solutions on the market. These factors include impacts, vibrations or high temperature during the operation of the machine and the regeneration process. For this reason, in case of dies used in the extrusion of aluminium profiles, traditional methods of permanent marking with use of presses [15] and a visual reading are still continued. Attempts to attach labels or other external elements often results in failure due to the aggressive environment in which the equipment functions. It can then easily lead to the damage or destruction of any electronic identification devices or less durable labels with the printing of the die's description.

Among others, barcode methods have become useful solutions due to the importance of recognizing and saving production data [16]. This technology is based on vision systems that allow for the reading of data using an image. The simplicity of these systems can be used in real-time and in different types of the production environments [17]. With the development of various fields of automation, numerous industrial applications for the barcode identification technology have been noticed. Smart management as well as the possibility of increasing quality and changing costs through online control of the production process deem this technology's application effective. The 2D barcode identification technology along with one-dimensional solutions are usually applied in the tool information in real-time query to carry out network management [18]. Two- and one-dimensional barcode identification devices that are connected to a global server in the production network become an important research topic and current solution, using a new technology to improve production efficiency and reduce artificial error in the field of advanced manufacturing technology [19]. Unfortunately, numerous limiting factors occurring at the production space during the regeneration process of tools significantly reduce the chances of reliable identification of markings [20]. Even a slight destruction leads to the loss of the ability to recognize their identification. In the case of alphanumeric markings, damage to the markings does not prejudge the impossibility of their identification, due to their visual legibility.

3. Experiment

3.1. Marking methods

Detailed studies regarding the range of limitation for two methods with alphanumeric markings (Fig. 3) were carried out by the authors using dies received from Extral Aluminium Company. The material WCL-V (1.2343 / X37CrMoV51) is

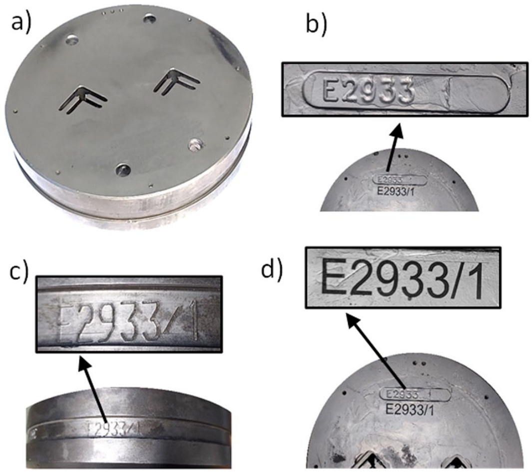

Fig. 3. Identification of the die tool using various techniques: a) view of a typical die for the aluminum extrusion, b) pressing method, c) engraving technique, d) laser marking method

used for this die and the chemical composition of this material has been provided in TABLE 1. It is alloy steel dedicated to hot-working processes, characterized by high hardness, resistance to tempering, the possibility of working at high temperatures and a low tendency to form surface cracks. The disadvantages might be sensitive to rapid temperature fluctuations during operation, low impact resistance and shocks. Still, the extrusion process takes place in a narrow temperature range without the danger of impacts, making WCL perfectly suitable for this application. WCL reaches 50-55 HRC after hardening, and the die is always nitrided after the standard heat treatment procedure. The tensile strength is about 1400 MPa (<150°C).

TABLE 1

The chemical composition of X37CrMoV51

C	Si	Mn	Cr	Mo	V	S	P
0,36-0,38	0,9-1,1	0,3-0,45	4,8-5,5	1,1-1,4	0,25-,5	<0,03	<0,03

A designation made by pressing method (Fig. 3b) causes this technique impossible to obtain sufficient contrast between the inscription and the surface of the die for automatic identification. The engraving technique (Fig. 3c) leads to a marking characterised by high durability, but mainly one used for visual identification. The lack of contrast between the inscription and the surface prevented the automatic identification of markings. It resulted from the formation of deep grooves arising from the laser energy absorption in the top layer and consequently, the occurrence of thermal processes (local temperature rise) and the melting and evaporation of material. Therefore, it was decided to apply a different technique based on the phenomenon of changing the structure of the top layer called laser marking [21]. This phenomenon rely upon the rapid heating and subsequent cooling of the micro-structure subjected to a laser beam. Local changes in the material ensuing from this treatment cause discolorations to the surface that enable methods of automatic identification (Fig. 3d). The laser marking method has been widely used in differing type of industry, demonstrate remarkable advantages for the fabrication high accuracy, and quality during marking [22].

3.2. Experimental apparatus

A portable vision system for the reading of die markings was designed. This measurement system is shown in Fig. 4, where specific elements have been described in detail. The system is equipped with a Besler Ace camera, where the image is transferred to a computer and subjected to digital image analysis. A machine vision lens is used to adjust the aperture and focus of the camera. A suitable contrast for the identification of characters can be obtained through scattered LED lighting. which falls perpendicular to the marked surface. The aforementioned equipment was set on a specially designed measuring arm with built-in sockets (Fig. 4b,c).

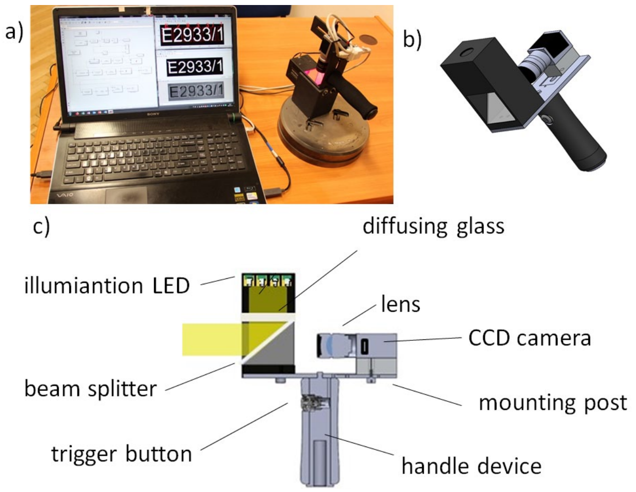

Fig. 4. The portable vision measurement system: a) the system along with program in Matlab, b) representation of the vision system, c) description of the elements

3.3. Numerical analysis

An application for digital image processing and its further analysis was developed in MATLAB. A numerical processing of this image is carried out to improve text quality that is part of the saved image. The main obstacle of text recognition is the heterogeneity of the image background, which may lead to the detection of other objects that were not part of the text after the conversion to binary representation using thresholding process. Shannon's entropy principle [23] is one of the tools used for image segmentation by thresholding. Therefore, given image A, that is set of picture pixels, and for the obtained probability distribution, we can determine the appropriate threshold t by minimizing the image's histogram. Defining Z^+ as the set of all positive integers and (x, y) as the coordinates of pixels in a digitized image A, then $Z^+ = \{0,1,\dots. I-1\}$ is the set of grey levels, where l is the total number of quantization levels. Furthermore, any pixel's brightness function (i.e. gray levels) can be defined as $h(x, y)$. For an image defined in this manner, the threshold level $t \in Z^+$, where the set $S = \{a_1, a_2\}$ will be two points defining grey levels and belonging to the collection of grey levels $a_1, a_2 \in Z^+$ As a result of thresholding operation, we will obtain a new function representing the binary image, according to the following relationship:

$$h_l(x,y) = \begin{cases} a_1 \text{ for } h(x,y) < t \\ a_2 \text{ for } h(x,y) > t \end{cases} \tag{1}$$

The resulting binary image has one bit of information, i.e. two levels of grey values $\{a_1, a_2\}$, obtained as a result of thresholding, for the value of the t threshold, and obtained as a result of using an arbitrarily selected value. The principle of maximum entropy is one of the tools used for image segmentation by thresholding. Assuming that X is a discrete random variable, i.e. the range $R = (x_l, x_2,...,)$ which set is finite or countable $p_i = P\{X = x_i\}$, $i = l, 2, ..., n$, then Shannon entropy is defined by equation [24]:

$$H(X) \cong H(p_1,\dots,p_n) \cong -\sum_{i=1}^{n} p_i \cdot \log p_i \tag{2}$$

where the random variable X represents the uncertainty measure of the stochastic field, and $H(X)$ represents its probability distribution function p_1 p_2, ..., p_n. According to the study [24] in the subject of image processing, image A can be considered a source of information to build a histogram that determines the desired probability p_i. Therefore, for a given image A that is a set of pixels of the image, and for the resulting probability distribution p_i Eq. (2), we can calculate a threshold t Eq. (1) by minimizing the described function of the histogram:

$$t = \underset{t \in Z^+}{\arg\min}\, H(X) \tag{3}$$

Subsequent steps are designed to format characters so that the OCR procedure would easily recognise the text. For this reason, mathematical morphological operations and non-linear operations of image processing were applied to modify the structure of the binary image (Fig. 5a). The implemented operations consist of the process of erosion, opening and thinning [25]. First of all, the option of removing separate objects whose area does not exceed the size of the smallest text character was applied (Fig. 5b). In this operation, small structures that occur separately in the background are removed, whereas similar objects consisting of characters are not modified. This action is carried out by *opening* γ_B for image X by using the structuring element B according to the following notation:

$$\gamma_B(X) = X \circ B = \cup_X \{B_x \mid B_x \subseteq X\} \tag{4}$$

where B is a structural element with a disk geometry and not exceeding the size of the smallest text character.

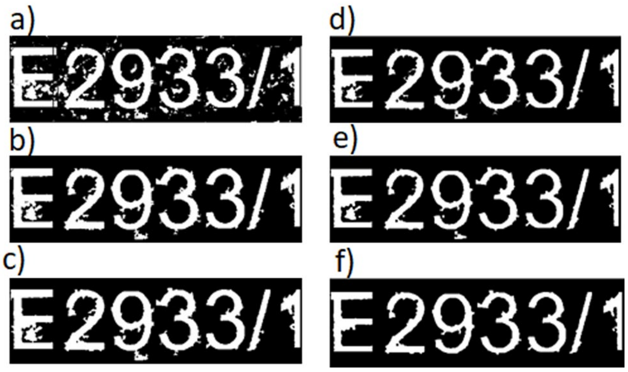

Fig. 5. Results of digital image processing: a) the result of binarization, b) removal of objects not connected to text, c) filling holes in text, d) thinning, e) the process of detaching objects from text, f) re-deleting objects not connected to text

The resulting gaps (co-called holes) in the image from the binarization process need to be filled. There are various methods of filling these gaps, however, the most effective approaches are based on the iterative application of dilation, where starting from a point inside of the missing region the aim is to fill in the whole area. Another technique is based on filling gaps of the binary image by removing all the pixels which are not connected to the image border [26]. The proposed solution in this area uses the previously described procedure Eq. (4) for removing objects (*Opening*) since the resulting gaps are small in relation to objects (Fig. 5c). Because of this, it was only necessary to further reverse the image, which is defined as X^c (where: X^c denotes the complement of X).

The resulting structures require additional operations that include *Erosion* ε_B for image X by using the structuring element B. This process will make lines thicker and easier to separate. Applying *erosion* leads to the separation of objects overlapping the text and their eventual removal by repeating the *Opening* operation (Fig. 5d,e). *Erosion* ε_B can be defined as the location of points $\boldsymbol{x}$, for a given configuration of the structuring element B fully contained within X region, while the origin B is placed in x, as notated:

$$\varepsilon_B\left(X\right) = X \ominus B = \left\{x \mid B_x \subseteq X\right\} \tag{5}$$

Reapplying *Opening* again Eq. (4) (for image X by using the structuring element B) leads to a clearer text without other adjacent, undesired objects (Fig. 5f). Eventually, all other small structural disturbances do not pose a problem in an accurate recognition of markings using the OCR procedure [27].

4. Results

As a result of the conducted studies, the influence of four main parameters on the final results was examined, including: the focus, image illumination, measuring arm settings relative to the marked surface and contamination of the surface with grime (e.g. accumulated dirtiness and disorder, Fig. 6a-f). These tests allowed for the determination of the sensitivity of the measuring system on variations arising from the operation of the measuring arm. The developed program managed to correctly identify the marked characters in all the presented cases. Even the last example (Fig. 6f), consisting of substantial surface grime, was correctly recognized by the program. Based on the obtained results on the effects of the four main parameters (i.e. focus, illumination, arm setting and surface grime) of the portable vision system, the following solutions were introduced. The solution proposed in the application is based on identifying text from external objects in the image, which is consistent with the task of recognizing markings on dies. The text detection algorithm uses maximally stable extreme regions [28]. All the elements that qualify in this way are filtered to exclude non-text objects. However, in the introduction about the binarization process and morphology carried by the authors, all irregularities are removed; hence, the OCR process is carried out without any disruptions.

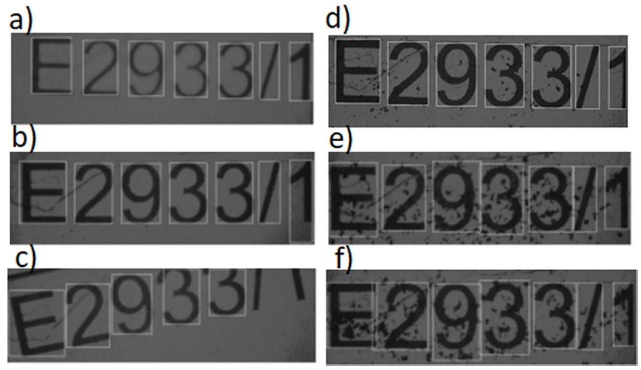

Fig. 6. The result of the measurements of the influence of the main parameters of the vision system: a,b) change in focus, c,d) positioning change, e.f) surface grime

Fig. 7 shows two examples of digital image analysis: with structural defects (Fig. 7a – typical for the surface die defects), and small dust particles on the surface (Fig. 7e – resulting con-

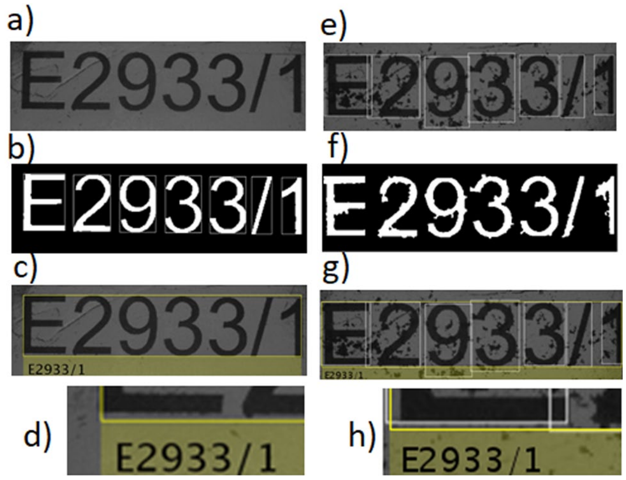

Fig. 7. The result of recognizing markings for two examples of character quality: a,e) the original result of the saved image with the marking, b,f) the digital image processing, c.g) the result of text recognition, d,h) OCR results (enlarged)

tamination, typically coming from the storage of dies). In both examined cases, after the mathematical morphology (Fig. 7b,f), and text recognition using OCR (Fig. 7c,g), the results of the text recognition were finally presented using Matlab graphical interface with a fully designed, automated procedure (Fig. 7d,h – enlarged).

5. Conclusion

The proposed solution includes comprehensive description as to increase the quality and organization of production in industrial plants using dies in metal forming processes. On the example of aluminium extrusion, three areas of research with innovative deployments were presented. In the first area of research, a laser marking technique was proposed, which is an example of contemporary achievements of controlling a consistent light source with very high power in a selected, narrow spectral range. In the second area, the authors present the concept of a portable vision system and advanced digital image analysis allowing for the reliable identification of alphanumeric determinations, which is necessary in industrial conditions. In the third area, the authors pay attention to the use of gathered data. The collected information regarding the current state of equipment or their current location allows for quick (online) decisions regarding planned orders or anticipated costs.

The solutions presented by the authors in the form of laser technology in portable measuring systems with advanced digital image processing and in conjunction with the proposed method of tool management can contribute to better planning of the production process, estimation of costs or overall risk assessment.

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