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A generic methodology to improve the control of forging process parameters

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Abstract. One of the common problems in forging processes is the lack of key process parameters control, as well as their identification. Certain controlled parameters exist, such as temperature or stroke length, which are usually identified and controlled through a systematic approach. Their selection depends particularly on the part to produce or on customer's constraints, rather than a rational approach. In this paper, a methodology is proposed to select the key process parameters. There are some methodologies which already exist, such as the DMAIC, which are used to determine the control parameters and their influences on the desired specifications. However, this approach has certain drawbacks. For example, the key parameters are selected by experts, which makes each case study time consuming. The aim is to develop a generic methodology to improve the manufacturing process in the forging industry. The methodology is represented as a decision support system that connects product specifications (geometry, absence of defects…) or other forging specifications (tool wear, involved energy...) to the process parameters. The latter will be able to define the key parameters, their values and their appropriate way of control. These links will be setup using the empirical rules and physical laws.

Introduction

A wide variety of metal parts are produced by forging process due to its productivity and the high mechanical characteristics of the forged part. The industrials want to produce parts that respond to the initial requirements; to do so, the mastering of the process is essential. To master the process, industrials define control parameters, not always through a rational way [1] and often applied to cases studies, for example to control the variation of the geometry of the workpiece [2], the wear of the tool [3] or the microstructure [4]. For industrials, the issue is to detect earlier a process drift in forging. This drift reflects an unfulfilled specification, either in the product or in the forging plan.

The aim of these researches is to propose a generic methodology that will capitalize knowledge, identify the key parameters to control and the monitoring means associated regardless of the case study and the chosen process. This paper describes the context of the current problem, some works realized in this field and the scientific and technologic obstacles. It explains the proposed methodology and the followed steps to master the forging process.

Context

The current problem is to identify the key parameters that will help in the process monitoring, in order to make the process robust, with parts without defects or with a correction system as efficient as possible to respond to variations and riskiness. The capitalization of knowledge is another target that can be reached by listing and classifying various defects and process parameters that exist in forging. These objectives should be achieved in order to master the forging process.

Current researches that are linked to the topic of mastering the forging process, focus on case studies where the production system is monitored using neural networks (ANN) [3,5]. Another method consists on using fuzzy logic. This method has been used for example to determine the force required to deform, in the case of a hydraulic press, depending on the position of the upper tool and the cylinder pressure [6]. The DMAIC approach is a methodology that permits to master the process by integrating the key parameters monitoring. It's applied in the case of forging [7,8] and can meet the targets but it has drawbacks that make it difficult to use, such as:

- The dependence of this method on experts, who decide on the choice of parameters in the definition phase.
- The loss of time involved in each case study.
- The independence of case studies treated.
- The lack of knowledge capitalization and the absence of a global vision on physical phenomenon and each process parameter itself.

The proposed methodology help in overcoming the disadvantages of the DMAIC mentioned above. A general description of the methodology is made through this article.

Description of the methodology

To master the forging process, the key parameters of the process must be determined. The work consists of implementing a decision support system enriched from the bibliography, forging expertise and case studies in which will be applied the DMAIC. This will yield:

- A faithful and an independent tool from the intervention of forging experts.
- A shorter time in making a decision. This will help in setting up a decision support system which can be used for the in-situ monitoring.
- A knowledge base based on treated examples or on examples found in the literature.

The idea is to control directly the process parameters at the origin of a process drift, instead of controlling the drift itself. The first step is to list defects (implicit specifications) that exist in forge. The second step, consist in identifying the physical phenomenon at the origin of these defects and the origin of a specification deviation in general. The process parameters are classified according to physical phenomenon, for example a flow problem is related to the quantity of material, the flow rate and the flow environment. The knowledge of these variables gives an idea of the process parameters that can be responsible of a modification, ie the lubrication, the initial volume, the surface roughness of the tool, etc. A final step consists in providing methods and means of control of these processes. To solve the problem, the idea is to act on the key parameters to identify and monitor, on the monitoring method and on the choice of the interesting process steps to control. To make this work, the process is considered as known, as the product specifications and the forging plan specifications should be.

To implement the methodology, the first step consists of listing the different implicit specifications (forging defects). These defects occur for a defined forging plan. Investigative work has been made on defects, and many of them can be found in the literature [9,10,11]. In the second step the cause of these defects or process parameters at the origin of these defects are defined. A correlation matrix can be set up to connect the defects to process parameters. The latter can be classified according to different areas that come into play during the process, namely; the manufacturing process, the product, the resources, the material and the environment. Fig.1 shows a possible representation of this matrix.

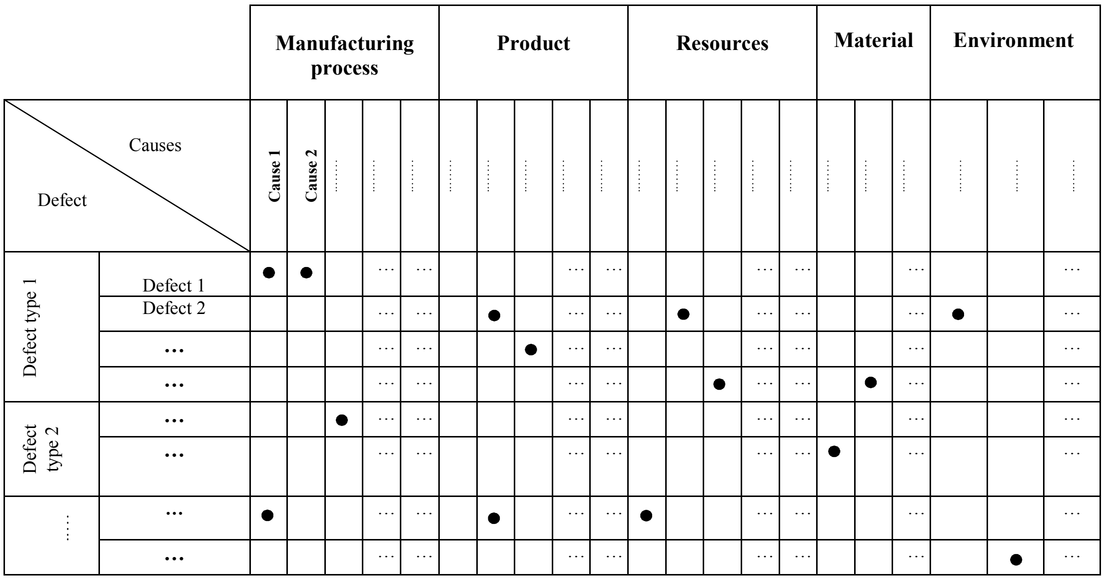

Figure 1. Correlation matrix that represent the relation between forging defect and process parameters

To synthesize all the forging defect and related causes found and described in the literature, a causes/consequences diagram is proposed (Fig. 2). This diagram links every specification deviation to responsible physical phenomenon, the causes of every physical phenomenon, with the percentage of probability that a cause can be responsible for this deviation, process parameters responsible for each cause, and monitoring devices to use for each process parameter. This structure helps in the implementation of a data processing tool that can be used as a decision support system. In addition, a color code currently allows defining qualitatively the difficulty level of implementation of every monitoring system.

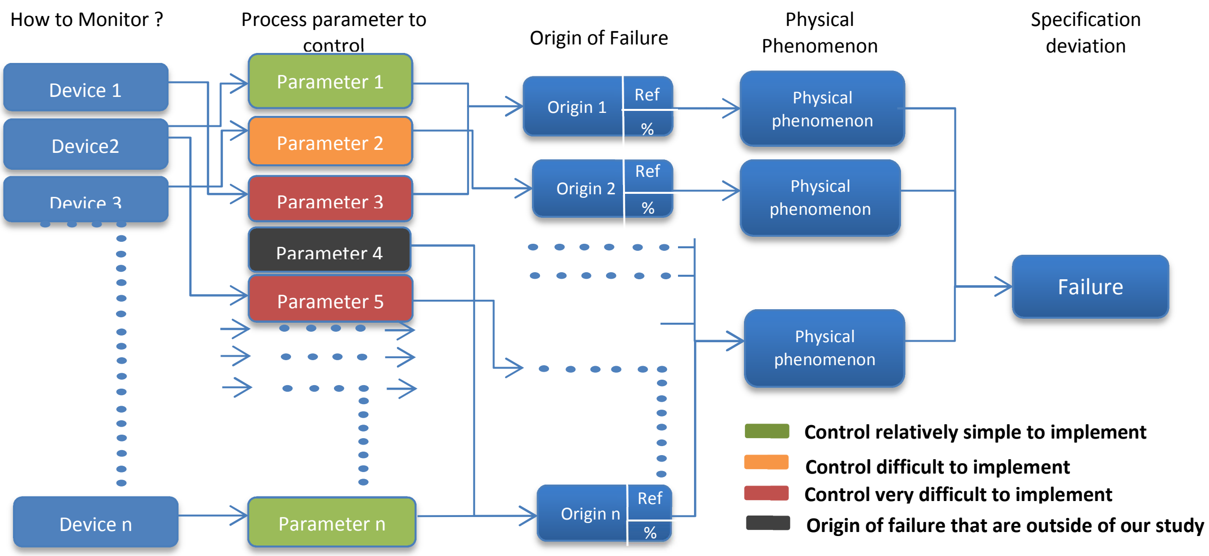

Figure 2. A causes/consequences diagram representing the relation between process parameters and unfulfilled specifications

For example, when an incomplete filling defect on the final part appears, the physical phenomenon responsible of it is the material flow. Each physical phenomenon is related to several causes, which in their turn are related to one or several process parameters. A poor material flow (physical phenomenon) can result from poor lubrication (the origin of the failure) which can be changed by modifying the quantity of lubricant (valve flow), and / or the distribution of lubricant on the tool surface. Another cause can be the origin of a flow problem, for example the position of the tool, which can be monitored via position sensors, but this can be difficult due to the vibrations that are involved in forging processes. Sometimes the problem can also arise from inappropriate choices, such as bad design of the forging plan, but it does not fall within the scope of the study and application of the methodology.

An ''Integrated DEFinition for functional models'' (IDEF-0) has been introduced in order to describe the methodology [12], fig.3 shows the overall form of the system used to master the forging process. The activity consists of determining the key parameters from the definition of the product specifications and the forging plan specifications.

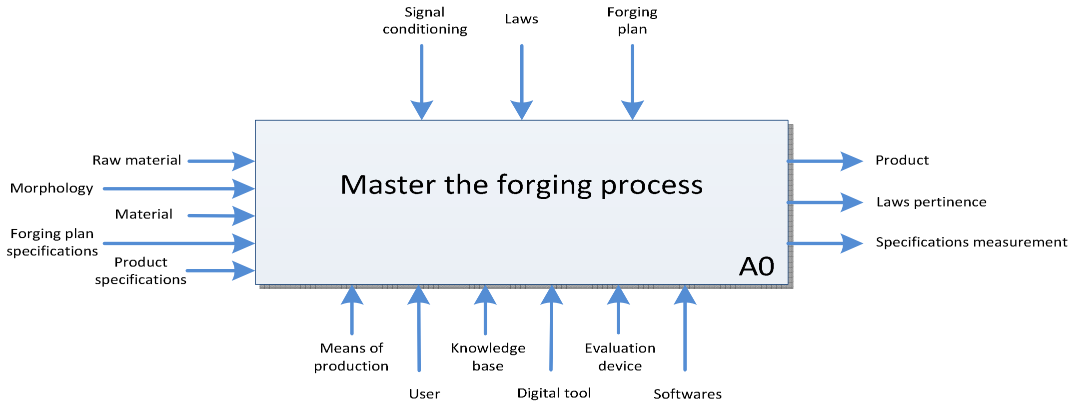

Figure 3. IDEF-0 diagram level A-0 of the mastering process system

Fig.4 details the activity A0 in three sub-activities:

- The determination of the key parameters (A1) → Decision Support System
- The forging of the part (A2) → Forging process
- The improvement of the prediction models (A3) → Learning system

The activity A1 represents a decision support system which determinates the key parameters to monitor in order to meet specifications (depending on the means of production used) in function of the entries (specifications, product information) using laws that came from literature or business rules. The outputs of the activity A1 represent the controlling mechanism of the second activity A2, where it is about transforming the raw material into finished product. The output of A2 activity is not only the product, but also the different measurements made on the desired specifications and the state of the process parameters during manufacturing. The third system (A3) is a learning system whose inputs are the initial specifications, the evolution of the state of the process parameters during manufacturing and the obtained measurements. This system is designed to implement laws describing the evolution of specifications based on process parameters. These laws will evolve in according to the results and should supply the decision support system with new laws or modifications of the old.

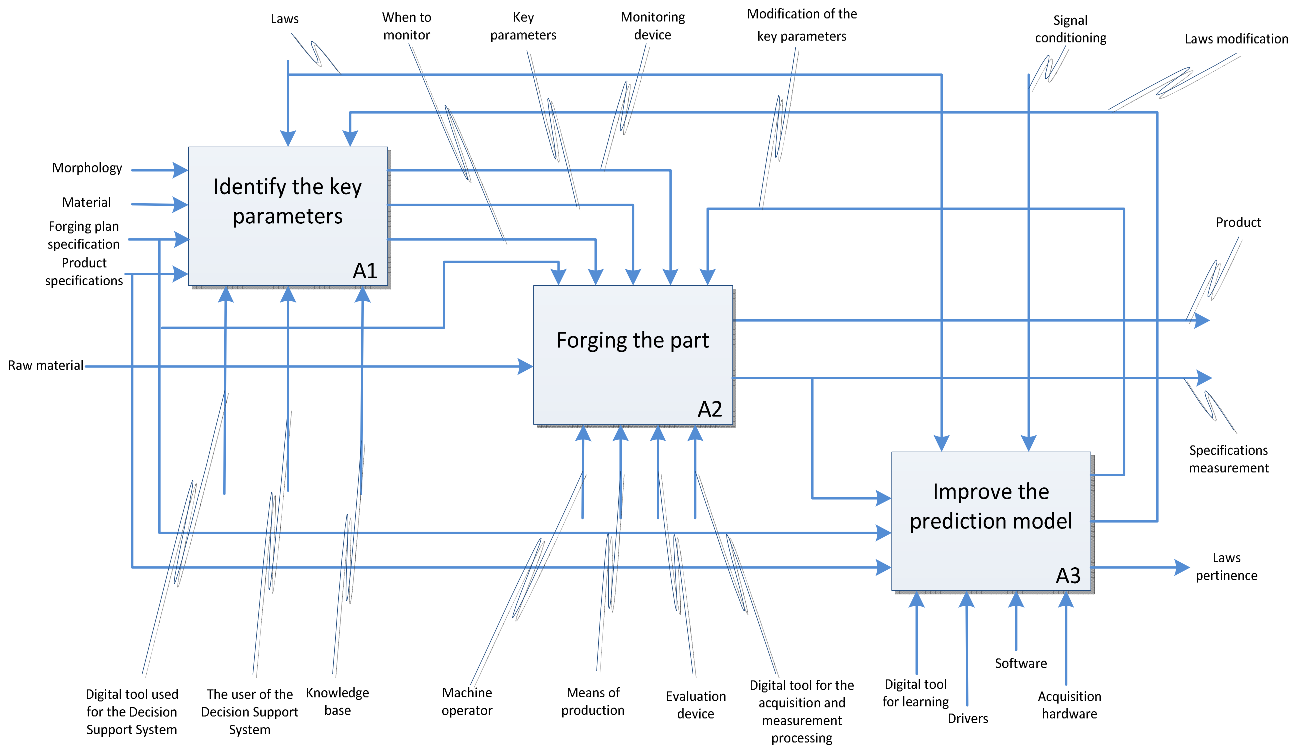

Figure 4. IDEF-0 diagram: the use of the decision support system and the learning system, activity A0: Master the forging process

Description of the activity A1. The activity A1 is a decision support system whose entries are the morphology of the workpiece in order to determine the geometrical specifications (tolerance on dimensions, length of the burr ...) [13], the material used, product and forging plan specifications. By applying business rules, laws found in the literature or laws implemented using the learning system (A3), the system will have as output: process parameters to monitor, when to monitor and which monitoring device has to be used. This system is controlled through laws and has as a support mechanism; the knowledge base, the user and the digital tool. Specifications vary depending on need (expressed by the user) and the system on which the methodology is applied. This system must be flexible and adaptable to the manufacturing system.

Description of the activity A2. During manufacturing, the input of the activity is the raw material. The outputs of the first system (A1) with the learning system (A3) are used as a controlling mechanism of the forging system. The support mechanism is formed of: the operator who ensures the application of the forging plan using the appropriate means of production and evaluation devices for measurement recovery. The system outputs are the product, the measurements made on the specifications and the measurements of the state of process parameter during forging. The forging system is seen as a process where the state of the workpiece changes gradually as it passes through the various stages of the process. Product specifications change during the process according to the means of production used, the deviation of a specification in a process step can lead to others in the following steps.

For example, in a hot forging process formed of 4 steps; cutting, heating, hot forging and deburring. A billet cut in the first step with a length less than the accepted tolerance may cause a filling defect during the hot forging step [9]. Each specification deviation in a process step can be related to a physical phenomenon, generated by a cause that can indicate the responsible processes parameters.

Description of the activity A3. The third system is a learning system that permits to determinate the modifications of the laws linking the variation of specification to process parameters and their values. This system has as inputs the initial specifications, the measurements on the specifications and the measurements on the state of the process parameters during forging. It has as support mechanism the digital tool and learning programs (based on neural networks for example). Outputs are in the form of modification of the laws or new laws that control the decision support system (A1). The second output is called "relevance of law," it is a percentage calculated from the prediction error of laws. The more the laws give results close to reality, the more the decision support system is representative and help in mastering the forging process [14,15].

Discussion

The proposed methodology provides a solution to the problem of mastering the forging process. The solution consist of determining the key parameters to monitor, via a decision support system, using laws and business rules that link the specifications to process parameters. Decision support system can never be effective if these laws and business rules don't change in function of the need and the means of production used. This is the reason why the establishment of a learning system downstream of forging process is a sine qua non condition for the effectiveness of this latter. The learning system in this context must be effective, several studies on neural networks have been used in forging process [3,5,16], and have to be developed in the future. The implementation of such a system will help in understanding how every means of production works, and will permit to make decision before starting the manufacturing in function of the state of the means of production.

Conclusion

The aim of this work is to master the forging process, through an implementation of a generic methodology. The latter will allow determining the key parameters to monitor in order to avoid deviation in product specifications or in the forging plan specifications. The work focuses first on the distinction between explicit specifications (expressed by the user) and implicit specifications (unspoken but hoped by the user). Then, physical laws and business rules are used to determine the key parameters, when and how to monitor according to original specifications. These laws are obtained through an analysis of the physical phenomenon at the origin of each specification deviation. The outputs of the decision support system constitute the control system of forging. A learning system is placed at the downstream of the production in order to modify or create new laws, with the aim of having a flexible decision support system and adaptable to needs. These laws are determined by measurements made on the state of the process parameters selected during manufacture, measures obtained on the specifications and the desired specifications.

The work done is related to the fact that the correlations between process parameters and specifications can be determined through an analysis of physical phenomenon. The interactions between the parameters must also be taken into consideration. Prioritization of the effects of process parameters on the specifications must also be determined. This methodology is applied in the field of forging, where the process control parameters is very difficult to implement in view of the number of parameters that come into play during manufacture (billet temperature, type of material, strain, strain rate ...). It can also be used in other areas with similar constraints, and where there are no explicit rules to define the process parameter values ensuring the mastering of the manufacturing process.

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