Towards Real Time Predictive System for Mechanical Stamping Presses to Assure Correct Slide Parallelism

Ivan Peinado-Asensi[1,2][a], N. Montes[1][b] and E. García[2][c]

[1] Mathematics, Physics and Technological Sciences Department, University CEU Cardenal Herrera, C/ San Bartolomé 55, 46115, Alfara del Patriarca, Valencia, Spain

[2] Ford Spain, Polígono Industrial Ford S/N, 46440, Almussafes, Valencia, Spain

Keywords: Smart Stamping Plant, Real-time Data Analysis, Machine Health Monitoring, Predictive Maintenance.

Abstract: Automotive companies are going through a rough time due to the decrease in the car sales market, therefore OEMs trend is cost reduction in the next years over improving efficiency increasing digitalization, implementing new industry 4.0 technologies to turn their facilities in smart factories. Within car manufacturing processes, stamping present many possibilities for development, in this paper an approach to bring stamping plants closer to smart factories is presented. The most common problems in stamping are unexpected breakdowns in equipment and poor quality parts produced, to avoid these problems corrective and predictive maintenance tasks are carried out to improve presses and tools performance. One of the critical maintenance tasks in press machines are parallelism, a malfunction in the kinetic transmission can lead to high cost and duration breakdowns. To monitor machine working parameters a novel method is presented using IIoT techniques, having access to machine working parameters in Real-Time to predict machine malfunction in order to reduce the number of breakdowns.

1 INTRODUCTION

Monitoring and Controlling press processes in the industrial stamping world has been widely developed to ensure machinery lifetime and high quality in the final product. But we are still having daily breakdowns in the production lines in the factory due to equipment failure and defects in the final product manufactured such as splits, necking and wrinkling among others. The previous research in control processes has followed four possible paths (Lim et al., 2013) to improve performance. One of them is the die try-out process where the objective is to analyze the tool (die design) and the working variables. The second one is controlling the blank holder force using finite elements analysis (FEM). Other is based in in-process control, a strategy to monitor the process inputs and outputs during the stamping process. The last one is a post-process control which part inspection is made to identify significant variables.

Stamping machines need periodical maintenance tasks to ensure correct functionality and avoid the mentioned breakdowns, we need to know the components status and fix them if required. Parallelism is one of the main maintenance tasks that require time and resources to carry it out and it is also important to ensure a correct slide motion. The imbalance in the slide is detected by the parallelism maintenance task, this is carried out by setting the press in the Bottom Dead Center without the die, placing the four position gauge under each slide corner and next raising the slide counterbalance pressure to lift the slide up and then drop it to the initial position again, this is the process carried out to measure slide clearance. Once the clearance is known, again in the BDC we take a slide corner as a reference and measure the distance of every corner to the floor, thus it is possible to know the balance difference in the corners. Once it is measured, the connecting rod feet are adjusted until the parallelism of the slide is balanced. As explained, the procedure is complex and requires a lot of time and resources.

In this research we are going to make an approach applying an in-process control methodology exploiting the amount of data available through connected devices employing Industry 4.0 technologies (e.g., Internet of Things, Big Data Analysis) monitoring the

[a] https://orcid.org/0000-0002-5603-5910
[b] https://orcid.org/0000-0002-0661-3479
[c] https://orcid.org/0000-0002-4210-9835

Peinado-Asensi, I., Montes, N. and García, E.
Towards Real Time Predictive System for Mechanical Stamping Presses to Assure Correct Slide Parallelism.
DOI: 10.5220/0010547203960402
In *Proceedings of the 18th International Conference on Informatics in Control, Automation and Robotics (ICINCO 2021)*, pages 396-402
ISBN: 978-989-758-522-7
Copyright © 2021 by SCITEPRESS – Science and Technology Publications, Lda. All rights reserved

variables of the machine, where exist up to 40 different variables to measure, among all the available data we will procedure to identify and classify the variables that are considered crucial in the process, directly related with the slide parallelism to obtain information to identify working pathologies. In the following sections it will be explained which variables and why are gonna be used to solve the parallelism problem, with the goal of having a full knowledge of the working state of the press in real-time. The problem statement is to verify if it is possible to detect the slide imbalance without requiring parallelism maintenance task, skipping the process and the use of the tools and sensors that are required to make it as the procedure presented in (Magraner, 2016). To do that a real-time monitoring tool has been developed to know the slide gravity center and the friction in the gibs. If the friction increase in some of the gibs or the slide centre of gravity is displaced we could ensure that the parallelism is not correct. Once the variables are selected among the forty available, will be of vital importance to verify if we can achieve to do accurate predictions. Afterwards it will be needed to define stamping working patterns to verify if the monitored variables are reporting appropriate information of the parallelism, if not it will requires to evaluate new ones.

The purpose of the research is to know the slide Gravity Center (GC) in order to control parallelism and avoid component wear due to malfunction with a predictive tool fed with data measures in Real-Time following a procedure called Maintenance Support System (MSS) (García et al., 2018), and once achieved, the following procedure will be to continue monitoring new variables that cannot be measured using the usual procedures. In this paper a predictive tool is proposed to know the GC of the slide in a cycle motion of the press using the signal data from the strain gauge available in the machine without required installation to monitor the process in real time. The motivation is to know the press working performance through the GC in every moment, being able to know the quality of the stamp punch, overloads, deviation of the slide parallelism and the slide travel motion to avoid premature wear due to friction in the press components.

The paper is structured as follows: In section 2, an overview of the research done in control and monitoring in industrial stamping. In the next section 3, we will explain the proposed physical model proposed with the data required to get the friction variable. In section 4 there is an explanation of how the data is monitored and the result of the models using real-time acquired data. In section 5 we will show the developed tool to find out the parallelism in real time. Finally, in section 6 we show the future work and the conclusion.

2 MONITORING STAMPING PROCESS

2.1 Equipment Description

Two main types of presses are used in sheet metal forming, mechanical (Single-action (SA) or Double-action (DA)) and hydraulic, both can be used in all operations carried out in stamping (blanking, deep-drawings and trimming) (Wagener, 1997). In Ford Spain stamping plant most of the presses are mechanical and the experiment of the research is being carried out in a mechanical SA press with a cushion system. The major difference between SA and DA presses is the eccentric drive transmission system and the blank holder force system. In SA presses as seen in figure 1 there is one slide for the tool and a cushion system as blank holder unlike DA presses that have an eccentric drive system with two slide displacements, one for the blank holder and other for the tool holder. Double effect presses have been used during years for deep drawing operations, but recently they have been replaced by hydraulic and SA presses with cushion because they are more effective in deep-drawing operations (Hoffman, 1998).

As seen in figure 1, a stamping press is manufactured of many different components such as the electrical engine which activates press motion, the eccentric transmission system which moves the slide upward and downward controlling the speed press, the clutch and brake hydraulic system, the slide counterbalance cylinders that help electrical engine to raise the slide and keep the torque of the activation system balanced in the cycle, the slide where the die is fitted for each production and height can be adjusted and also the gibs in each of the press columns to guide the slide.

2.2 Process Control in Sheet-metal Forming

There is much research based in methods that they use data for monitoring working process, this research mostly in close-loop and in-process control systems. In last decades it has been easy to find research about close-loop control as the one developed by (Siegert et al., 1997) (Yagami et al., 2004) (Viswanathan et al.,

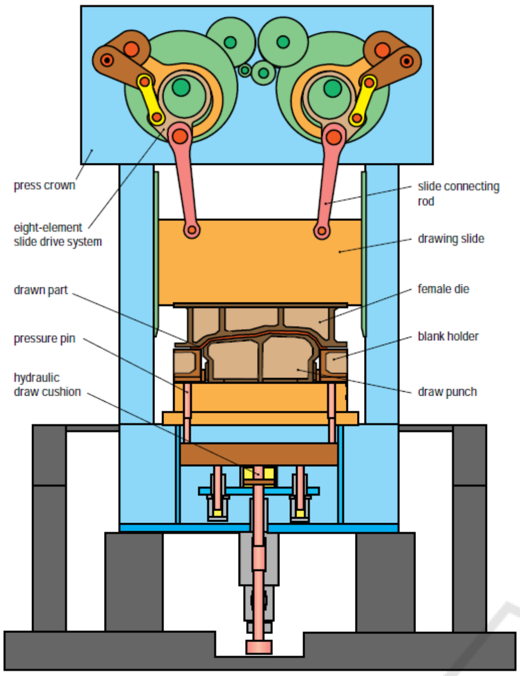

Figure 1: Single-action mechanical press.

2003) in which the springback effect of the material is controlled by the Blank Holder Force applied, controlling the material flow when deep-drawing (Endelt et al., 2013) and also eliminating the wrinkling and fracture in rectangular parts (Ahmetoglu et al., 1995). Also non-destructive test (NDT) have been used to monitor data, in the case of (Ng et al., 2007) to diagnose the stamping quality, the 3D thermal distribution was analyzed, using the electromagnetism physical principle by installing electromagnetic coils in the die surface (Shang and Daehn, 2011). There is much research based too on Acoustic Emission in order to detect bad parts (Song et al., 2016) or to detect tool wear (Ubhayaratne et al., 2015).

Regarding to in-process control systems, in the study carried out by Hardt and Fenn it was possible to detect differences in material input such as lubrication and material thickness (Hardt and Fenn, 1993), that was a breakthrough in control monitoring because it was possible to identify new variables in stamping process. Hardt *et all.* used the data monitored from the force punch combined with a previous close-loop control developed to control the blank holder force. Other effective process control designed was the one proposed by (Hsu et al., 2002) in which they take into account blank holder pressure, the sheet metal features and the punch force showing that the process can maintain the same punch force trajectories with different lubrication conditions, but machine control cannot.

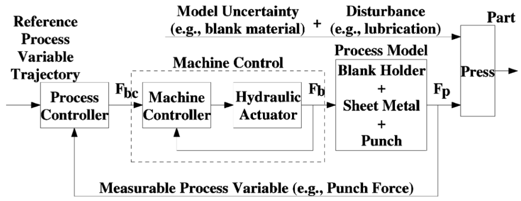

Figure 2: Process control of sheet metal forming.

The proposed procedure is focusing on taking a step forward, the idea is following in-process techniques by monitoring the required data to analyze working performance using Industry 4.0 technologies, but to carry it out a huge investment is needed in order to buy and install proper equipment to get accurate data and centralize the measurement system in one platform. Furthermore, due to the currently situation in the automotive sector the OEMs are planning to reduce costs. It is true that by increasing digitalization and optimizing the efficiency of productions the costs can be reduced, but a large initial investment is required anyway. Therefore, we are going to apply Industry 4.0 techniques avoiding this initial investment by acquiring the data from the sensors already installed in the presses of the plant, and by developing the software in site to analyze the data and send alarms to predict breakdowns.

3 MATHEMATICAL MODEL TO MONITOR STAMPING PROCESS DATA

Taking as starting point that the bad parallelism and the imbalance in the transmission system leads to a premature wear of the different components in the press and this wear is caused because of the friction between them, we can conclude that friction and imbalance are directly relate. The aim of the data acquisition is to obtain curves of all the available measured variables in the press, at least on value per each press position, this means 360 values in a curve shape of tonnage force, counterbalance pressure, overload pressure, cushion pressure, etc. Therefore relating all this data in a physical model could be possible to obtain the friction force of different components.

Thus a physical model will be proposed in this section to monitor the friction force variables in a press. The model is going to be set in three stages. Firstly, a model describing the downward motion where the friction in the gibs and in the eccentric transmissions systems can be obtained. Secondly, the deep-drawing where the friction of the die surface with the blank surface could be modelled and in the third stage, the upward motion of the slide where the same friction force can be obtained as in downward motion. So following the procedure used to monitor the GC and thanks to the data acquisition system, a physical model is presented to know the friction in the slide gibs in real-time during the downward motion.

In picture 3 the loads considered in the model are shown. The proposed model will be used to find out the friction force in each press corner. So if we consider the system as static in every press position degree, where there is no downward movement and therefore we will consider there is no friction in the gibs, so for one corner it results,

$$\frac{F_{C_i}}{2} - F_{s_i} = \frac{m}{4} \cdot a_x, \qquad i = 1. \tag{1}$$

Where F_C is the slide counterbalance force, F_s the press force applied in the slide measured with the tonnage gauge sensor, m the upper die mass and a_x the acceleration of the slide in the downwards motion. The model is used to describe the physical behaviour in every corner of the press as described in picture 3.

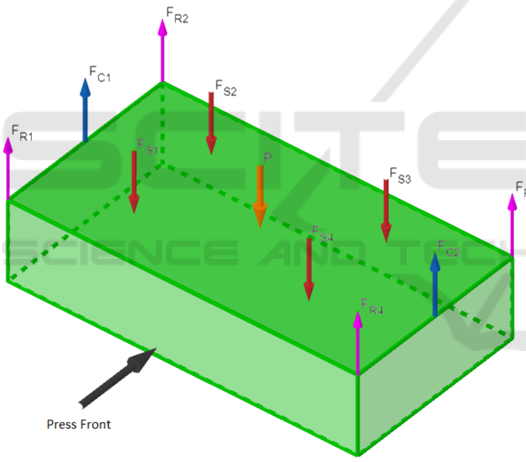

Figure 3: Slide loads considered.

$$F_{R_i} + \frac{F_{C_i}}{2} - F_{s_i} = \frac{m}{4} \cdot a_x, \qquad i = 1. \tag{2}$$

Considering the forces applied by the components involved in the downward motion of the slide being F_R the gib friction force. Now it is shown the result of the physical model for the entire mobile system,

$$\sum_{i=1}^{4} (F_{R_i} - F_{s_i}) + \sum_{i=1}^{2} F_{C_i} = m \cdot a_x \tag{3}$$

As it can be seen, the only parameter that is not known is the friction force, which will be obtained from the model proposed. Applying this equation to every press position degree from 320^o to 90^o we are able to control the friction force existing between the slide and the gibs.

4 DATA ACQUISITION PROCESS

The standard which has already been implemented by Ford in Valencia Factory to program the PLC to get the data explained in (Garcia and Montes, 2019) allowed to get direct connection to the already installed sensors by the press manufacturer. Saving money in the installation because the sensors to get the info are already installed in the press except the acceleration, the only variable needed that was not previously monitored but whose installation was really easy as explained below.

The challenge at this point is to have enough scan speed in the PLC to read all the required data in a stamp cycle, so due to the slide motion it is carried out in more or less 3.5 seconds and 360 values per sensor which need to be read by the PLC and if there are nine variables it is exactly 3240 values, it requires around 1 ms second of scan speed per cycle. After several tests carried out in the installed PLC, it was proved that no data was missing in the cycle. Therefore, the data collection started to obtain the curves of the data per cycle to calculate the friction force.

To know the slide acceleration parameter, of vital importance in the proposed model, a cheap and simply solution has been carried out, having access to an important variable without significant expense. An accelerator sensors has been installed (detail in figure 5) in each corner of the slide, having the acceleration in the whole motion cycle, the sensor was connected through a switch to the PLC to be able to collect all the data where the other variables are monitored. The tonnage data is acquired from the gauge sensors installed in the columns of the press, there are four gauge sensors installed which send the data through the Helm switch to the PLC. The slide counterbalance force has been read from the pressure sensor installed in the pneumatic circuit of the system. There is just one measure that is why in the model is divided by four, taking it as proportional in each corner.

5 REAL-TIME PREDICTIVE TOOL

The online tool presented is currently working with tonnage force data, the press is equipped with a load gauge sensor in each one of the connecting rods which allow us to know the press force applied in the cy-

SCITEPRESS SCIENCE AND TECHNOLOGY PUBLICATIONS

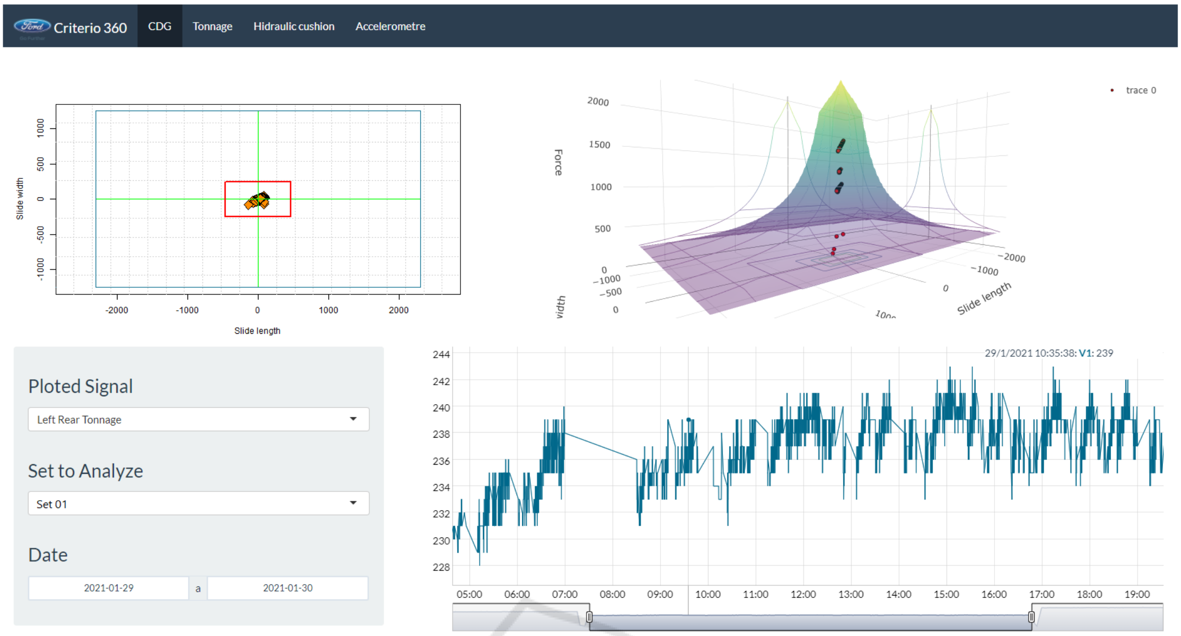

Figure 4: Gravity Center in Real-Time.

cle. As far as it is known with the force carried out by the press in each of the four rods it is possible to obtain the gravity center of the slide. By getting the data from the PLC and applying the calculus in our tool we can find out the gravity center at every point. The tool shows the gravity center in real-time at Bottom Dead Center press position (180 degrees) where the maximum press force is applied, depending on the produced part on the machine where the experiment is taking place the maximum force can be up to $2.1 \cdot 10^6$ (kg), close to the press limit which is $2.5 \cdot 10^6$ (kg). Knowing the gravity center of a squared object where some forces are applied is trivial, thus the process of implementing it in the software, developed in site, and also having the Ford standard platform to connect the machine data to the data based in the cloud was not a big deal, the result obtained is shown in picture 4.

Different areas are shown in the online platform 4, at the top left you can see the GC displacement of the slide in 2D at BDC press position, the red square indicates the press working limit for that applied force and the blue square delimits the size of the slide. At the top right we can see the GC plotted in 3D, where the z axis indicates the press force for each stamped part. The graph at the bottom shows the data obtained from the sensor signal selected. There is also a menu where we can choose the date of the production when the data needs to be analyzed, the sensor type needs to be analyze and also to classify the data depending on the manufactured body part, because depending on the body parts produced the data can vary due to material and die characteristics. There is also the option to visualize the GC of a cycle curve as you can see in picture 6.

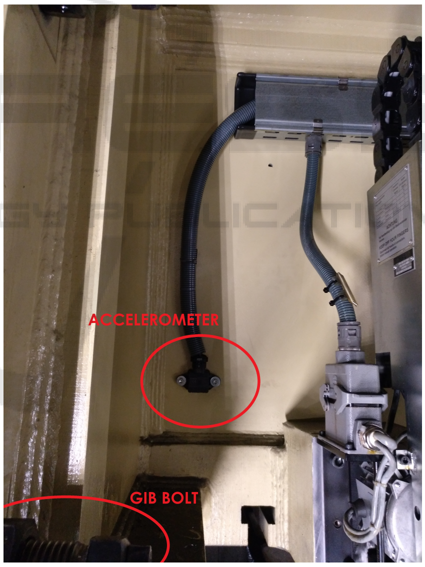

Figure 5: Accelerometer sensor location.

The tool purpose is monitoring the gravity center and check if there is any variation or pathology that appears just in time which can give information about the machine status. It is well known that a deviation of the slide balance can lead to premature wear in the eccentric motion transmission system, wear of the die surface and also in the slide gibs, caused by friction

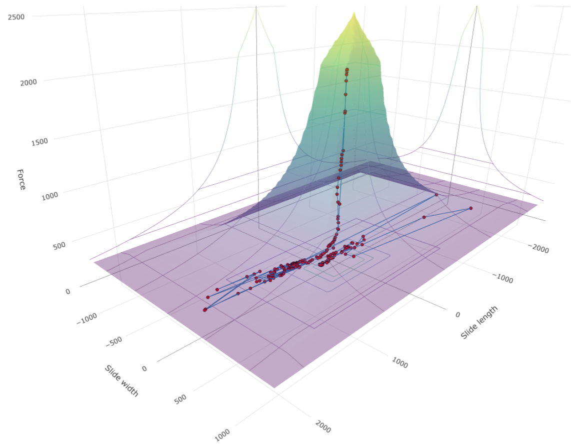

Figure 6: GC of a cycle.

increasing that may cause a lot of problems in the produced parts and the machine function. Knowing the GC information in Real-Time can give us an advantage to reduce maintenance activity, reduce mechanical wear and reduce the set up press working force and avoid parallelism checking extra works, all of that can be achieved directly. Indirectly, electrical consumption and repairing time can be reduced, breakdowns can be predicted and the life of the equipment extended. All the improvements listed can bring cost reductions.

5.1 Health Machine Monitoring

The next step is to know when the machine stops operating under normal conditions and to identify the problem that makes this happen. To do that, we will send an alarm when the GC deviates from the predefined boundaries. As seen in picture 7

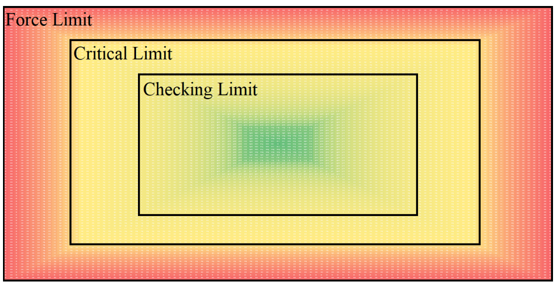

Figure 7: X-Y section of limit surface force in 2D.

while the GC is still inside the green area we are going to consider it to a normal function, once it reaches the yellow area it will send an alarm to know the behaviour of the press and check whether it is a random hit with imbalance or a cumulative event of hits out of the normal working area, if this happens a technician will be sent to check the machine status. When the hit reaches the red area the same procedure as in the yellow area will be carried out but with an exhaustive inspection and finally if it goes beyond of the force limit line, the press will stop automatically.

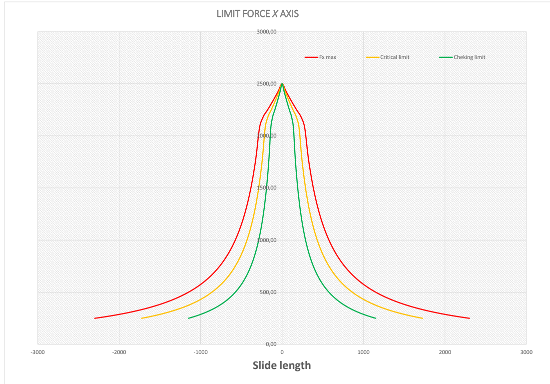

Figure 8: X-Z section defining status limits in X axis.

Here in picture 7 we define the limits to identify when the parallelism is deviating, these limits are defined inside the red square at the top left graph in picture 4. To show the defined alarm area more precisely in picture 8 you can see the surface in 2D from a right profile view.

The same is defined in y axis and the result of the shape of the different alarm area volumes can be considered as proportional surface with reduced volumes inside the force limit surface that you can see at the top right in picture 4. From the 360 points of the GC obtained per cycle it will considered the percentage of the points that there are in different area. The result of the example curve showed before in the picture 6 there is a 100% of the values inside the green volume.

6 CONCLUSION

The research will continue monitoring the proposed data in the physical model that is left to measure, following the same procedure carried out on the tonnage force (such as counterbalance force and acceleration) in the whole cycle and simulate the stamping cycle to get the friction force. The cycle is divided into 3 stages. The first one, downward motion to know the friction in the gibs, the second one is the same in upward motion and the third one will be the deep-drawing when more variables will be considered, such as the the hydraulic cushion force, to get the friction force between the die surface and the blank material. To do that first it is required to extract a big amount of data, check if the PLC is able to sent the data without

SCITEPRESS SCIENCE AND TECHNOLOGY PUBLICATIONS

loss of information, for later process the information in our predictive tool.

Using industry 4.0 technology a tool developed to control the machine in real time has been created, following the OEM trend of transform their current manufacturing facilities in smart factories. The tool developed works as expected in real-time and give accurate and valuable information about the slide state working, been able to control parallelism and friction in the gibs reducing maintenance activity and premature wear altogether with reduction of electrical consumption. Furthermore the developed tool result as a robust and powerful method that gives a lot of opportunities when talking about predictive maintenance and knowing the machine health, taking the lead predicting breakdowns.

ACKNOWLEDGEMENTS

This study was supported by the Universidad CEU Cardenal Herrera, Ford Spain S.L. and Fundación para el Desarrollo y la Investigación (FDI), Spain, which the authors gratefully acknowledge.

REFERENCES

Ahmetoglu, M., Broek, T., Kinzel, G., and Altan, T. (1995). Control of blank holder force to eliminate wrinkling and fracture in deep-drawing rectangular parts. *CIRP annals*, 44(1):247–250.

Endelt, B., Tommerup, S., and Danckert, J. (2013). A novel feedback control system–controlling the material flow in deep drawing using distributed blank-holder force. *Journal of Materials Processing Technology*, 213(1):36–50.

Garcia, E. and Montes, N. (2019). Mini-term, a novel paradigm for fault detection. *IFAC-PapersOnLine*, 52(13):165–170.

García, E., Montés, N., and Alacreu, M. (2018). Towards a knowledge-driven maintenance support system for manufacturing lines. In *ICINCO (1)*, pages 53–64.

Hardt, D. E. (1993). Modeling and control of manufacturing processes: getting more involved.

Hardt, D. E. (2017). Forming processes: Monitoring and control. *The Mechanical Systems Design Handbook: Modeling, Measurement, and Control*.

Hardt, D. E. and Fenn, R. C. (1993). Real-time control of sheet stability during forming.

Hoffman, H. (1998). *Metal forming handbook*. Springer Science & Business Media.

Hsu, C.-W., Ulsoy, A., and Demeri, M. (2000). An approach for modeling sheet metal forming for process controller design. *J. Manuf. Sci. Eng.*, 122(4):717–724.

Hsu, C.-W., Ulsoy, A., and Demeri, M. (2002). Development of process control in sheet metal forming. *Journal of Materials Processing Technology*, 127(3):361–368.

Lim, Y., Ulsoy, A. G., and Venugopal, R. (2013). *Process control for sheet-metal stamping*. Springer.

Lim, Y., Venugopal, R., and Ulsoy, A. (2012). Auto-tuning and adaptive stamping process control. *Control Engineering Practice*, 20(2):156–164.

Lim, Y., Venugopal, R., and Ulsoy, A. G. (2008). Advances in the control of sheet metal forming. *IFAC Proceedings Volumes*, 41(2):1875–1883.

Lim, Y., Venugopal, R., and Ulsoy, A. G. (2010). Multi-input multi-output (mimo) modeling and control for stamping. *Journal of dynamic systems, measurement, and control*, 132(4).

Magraner, E. G. (2016). *Análisis de los sub-tiempos de ciclo técnico para la mejora del rendimiento de las líneas de fabricación/tesis doctoral presentada por Eduardo García Magraner; dirigida por Nicolás Montés Sánchez*. PhD thesis, Universidad CEU-Cardenal Herrera.

Maugin, G. (1980). The method of virtual power in continuum mechanics: application to coupled fields. *Acta Mechanica*, 35(1):1–70.

Ng, Y.-M. H., Yu, M., Huang, Y., and Du, R. (2007). Diagnosis of sheet metal stamping processes based on 3-d thermal energy distribution. *IEEE transactions on automation science and engineering*, 4(1):22–30.

Shang, J. and Daehn, G. (2011). Electromagnetically assisted sheet metal stamping. *Journal of Materials Processing Technology*, 211(5):868–874.

Siegert, K., Ziegler, M., and Wagner, S. (1997). Closed loop control of the friction force. deep drawing process. *Journal of materials processing technology*, 71(1):126–133.

Song, J., Kim, S., Liu, Z., Quang, N. N., and Bien, F. (2016). A real time nondestructive crack detection system for the automotive stamping process. *IEEE Transactions on Instrumentation and Measurement*, 65(11):2434–2441.

Ubhayaratne, I., Xiang, Y., Pereira, M., and Rolfe, B. (2015). An audio signal based model for condition monitoring of sheet metal stamping process. In *2015 IEEE 10th Conference on Industrial Electronics and Applications (ICIEA)*, pages 1267–1272. IEEE.

Viswanathan, V., Kinsey, B., and Cao, J. (2003). Experimental implementation of neural network springback control for sheet metal forming. *J. Eng. Mater. Technol.*, 125(2):141–147.

Wagener, H.-W. (1997). New developments in sheet metal forming: sheet materials, tools and machinery. *Journal of materials processing technology*, 72(3):342–357.

Yagami, T., Manabe, K.-i., Yang, M., and Koyama, H. (2004). Intelligent sheet stamping process using segment blankholder modules. *Journal of Materials Processing Technology*, 155:2099–2105.