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In Process Measurement Techniques Based on Available Sensors in the Stamping Machines for the Automotive Industry

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Abstract. It is currently going through an industrial period in which connectivity, data collection of the process and its understanding to optimize it is becoming more and more common. The automotive industry is no exception as we are on the way towards connected factories where the digitization of the stamping process is a trend followed by manufacturers. A common problem often encountered is the high cost required to develop solutions by using this technology. Obtaining parameters of the manufacturing process is a challenge on many occasions. New solutions have been proposed from an opposite point of view, i.e., we evaluate what information can be extracted from the equipment and from the data obtained we can bring forward the possible tools to be developed without the need for extra investment. This article shows the verification of an experimental process, previously developed, with which we intend to find out the status of the press during the drawing process for each cycle that is carried out during production and also the status of the equipment at all times, up to the point of detecting if there is any problem both in the die and in the mechanical components of the press and verifying it with the developed tool, showing that we can know the status of the equipment by monitoring the data in real time.

Introduction

New industrial trends are moving towards Industry 4.0 techniques where the acquisition of the data from installed sensors to obtain new information from the process has become usual [1]. Following the same trend, we are going to leave out the research that use economic resources by installing new sensorization to obtain as much information as possible from the sensors installed as standard in Real-Time presses. This trend is justified by two reasons. The first, making the proposed solutions as cheap as possible and second, making the results more viable. Currently there are scientific solutions that are not feasible at an industrial level because putting them into operation implies a large investment in facilities and maintenance of the installed equipment, therefore, they are never used in the industry.

The stamping process is the most used technique in the automotive world for manufacturing the car body parts. Used for decades, it has great advantages over other processes due to its volatility and mass production capacity. The stamping process is made up of more than 40 variables that directly or indirectly affect the process. For this reason, Condition Monitoring and Process Control techniques in stamping have been widely developed to ensure machinery lifetime and quality product [2]. Despite the effort there are still daily breakdowns due to equipment failure or faulty manufactured parts.

Stamping presses and their equipment need periodic maintenance tasks to correct working status with the aim of avoiding the mentioned breakdowns. A typical problem is the appearance of imbalance in the press slide, that it is detected by a complex maintenance task to measure the slide parallelism, without this correction it is possible to lead to a major breakdown in the eccentric transmission system and the impact to repair it is very high for the company, that is why this task is one of the main maintenance processes. To carry it out first the press is set in the Bottom Dead Center (BDC) without the die, placing four gauges under each slide corner to adjust the rods, then raising the slide counterbalance pressure to lift the slide up to drop it to the initial position again, so 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 and the difference between each corner of the slide to the floor is the same. As explained, the procedure is complex and requires a lot of time and resources.

The Stamping Plant facilities at Ford Spain most of the presses are mechanical and the test of the research is being carried out in a Single-action (SA) press with a cushion system. The difference between SA and Double-action (DA) presses is the eccentric drive transmission system and the Blank Holder Force (BHF) system. In SA presses 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-action 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 [3].

To have an adequate monitoring of the process we need to obtain as much data as possible and the application of methodologies for its measurement requires a large number of samples. For this reason, data acquisition presents a great challenge today, and in the stamping process in particular, since in stamping plants of car body parts it has not been sufficiently researched yet [4].

For the development of this research, a real-time monitoring tool has been developed for the parameters accessible through the PLC that operates the press. Variables such as Tonnage load, Counterbalance Pressure and Overload Pressure are being monitored among others. The data are recorded in a database and shown by an interface as seen in Fig.1.

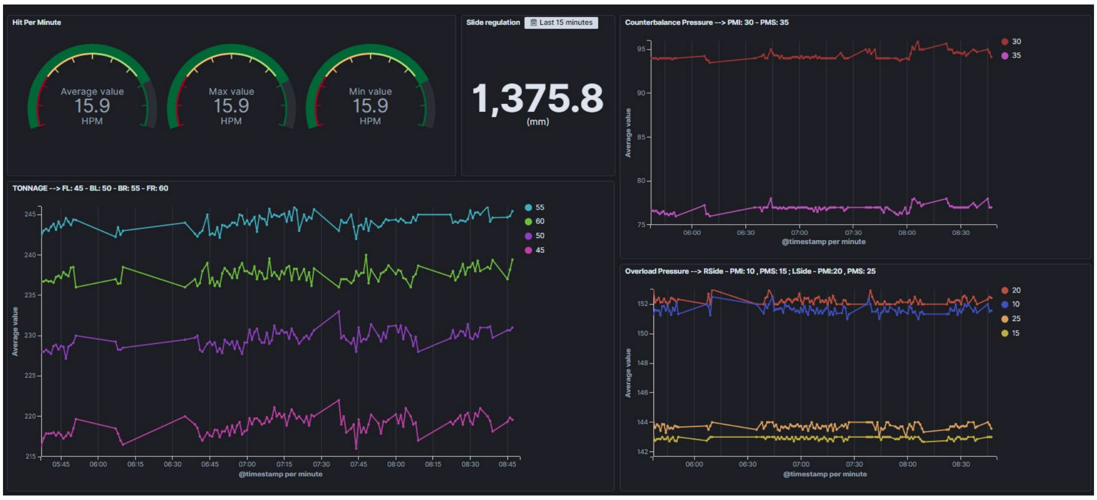


Fig. 1: Stamping Process Parameters in Real-Time

The objective of our research is, through the data available in the press, to optimize the process from the point of view of machine health, part quality and energy saving. This paper focuses on optimizing the process from the machine health point of view and shows the experimental validation of the tool developed to monitor the center of gravity of the slide [5] in order to relate it to the press imbalance when it moves within previously defined working limits.

Methodology

In the world of stamping, the working parameters for the production of the different car body parts are obtained through simulation, where from some inputs such as properties of the material to be used, geometry, type of lubrication, etc., we can obtain the outputs to be configured in the press such as the stamping speed, materials, tonnage, etc., to produce parts within quality margins. But this is not always true, the theory shows that with the same input parameters the final product must have the same stretch distribution at each point along the part, but this is not always the case and parts with defects may appear randomly so that they have to be sent for repair or directly disposed of as scrap metal. This can be due to different factors such as die wear [6], change in the properties of the material in the sheets obtained from the end of the coil or even due to a bad working condition of the press. The methodology to follow in the research is the development of condition based monitoring tools to diagnose the equipment status in real time with the aim of reducing costs [7].

The first step in designing the monitoring tool is to select the outputs of the process we have, which can provide us with more information. One of the outputs that can provide more information is the tonnage produced by the press, which gives us information throughout the entire work cycle [8]. The tonnage has been used in the literature for the diagnosis of the process, applying different techniques for the detection of pathologies such as statistical analysis [9], installing new sensors to perform measurements that can be related to tonnage [11] and even applying Deep Learning techniques [10, 12], all of them used in order to obtain more knowledge of the process.

The load exerted by the press during the stamping process varies significantly when modifying any of the parameters we have mentioned, i.e., if the thickness of the material increases, the load exerted by the press will be greater, if we reduce the force exerted by the presser, a greater amount of material will flow into the die [13] and less effort will be made by the press for forming the sheet and vice versa, and so on with many working parameters. In short, tonnage is a highly sensitive variable to any change in the process parameters that can affect the machine health and the quality of the part.

For this reason, in this paper a tool is developed to know the parallelism of the slide during the press at all times through the real-time monitoring of the tonnage, taking as a starting hypothesis that if the parallelism is constant, that is, there is no variation or a trend that modifies the parameters stored for each die, the mechanical elements of the press will work correctly and on the other hand, if for one or more dies we obtain a parallel slide different from the usual one, this means that a malfunction has been detected in one of the parts, either components of the die or the press and therefore the equipment should be checked.

According to the experience of the maintenance mechanics at the Ford Almussafes plant (Valencia), having a correct parallelism of the slide is vital to ensure that the different mechanical parts of the press and the die work correctly, in this way we will avoid any unforeseen failures and reduce wear on the die surface since a fault in the eccentric drive transmission system in one of the presses of the plant can be a great unforeseen event as explained previously. To this should be added the inconveniences that this implies for the production programme of the different vehicle parts that can be manufactured by said press, causing inevitable chaos in the plant during the repair period.

Tonnage Measurement

Taking into account the above and in order to monitor the gravity centre of the slide at all times, the following has been done: a block programme has been designed to be programmed in the PLC to store a datum for each position of the cycle, this being divided into 360 degrees, which would be a turn of the main axis that occurs in a cycle and in order to define the position in which the slide is found the 360 position has been defined in the Top Dead Center (TDC) and the 180 position in the BDC, therefore with these we will obtain 360 data per sensor each cycle. Each cycle has a duration of approximately 4 seconds, so we would be capturing 1 datum every 10 ms approximately per sensor. The datum is sent to the PLC through a high speed analogue communication card. Once the cycle is finished, the data packet is sent via Ethernet to the Data Exchange Device (DxD) where we already have access to the data. In Fig.2 we can see an example of the tonnage signal we are measuring for each cycle.

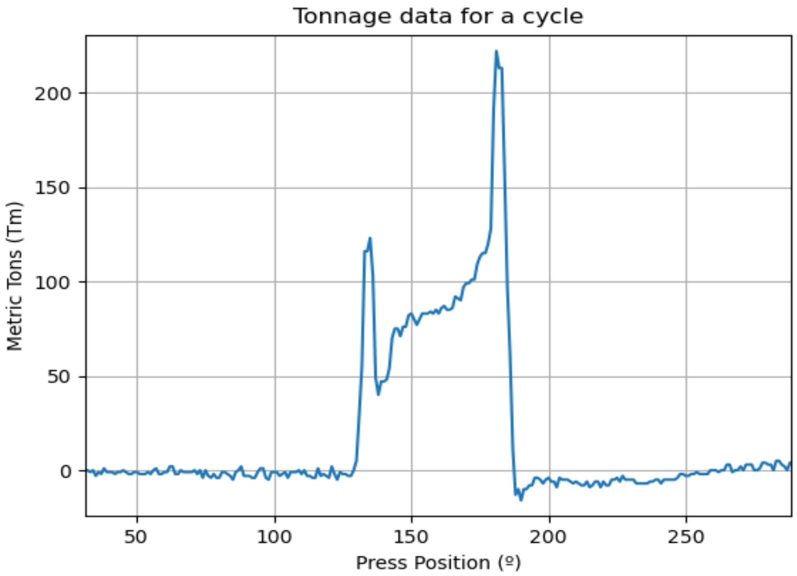


Fig. 2: Tonnage data plot

Once the tonnage measurement has been carried out, the calculation of the gravity centre of the tool holder has been applied for each press position, using the equation for the calculation of the gravity centre for composite bodies, taking as masses the value of the tonnage reaction and the distances from the connecting rod feet to the centre of the slide, so we have:

$$GC = \frac{\sum T_i D_i}{\sum T_i}, \tag{1}$$

where:

T_i is the measured load of the tonnage applied in the plane of the axis x
D is the distance from the applied force to the centre of the slide

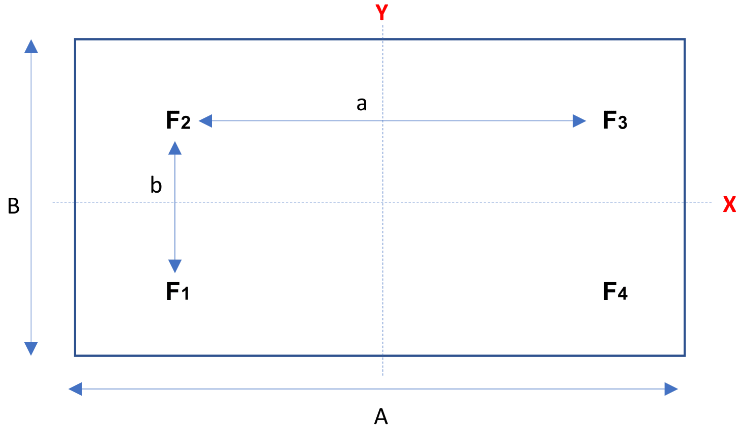


Fig. 3: Slide Sketch

Equation (1) is specified for the calculation of the GC in each axis where, for GC_x is applied $D = a/2$ and for GC_y, is applied $D = b/2$, see Fig.3.

Fig.4 shows the representation of the resultant of the gravity centre in 3 dimensions, where the x and y axes are the deviation of the GC (mm) in each press position and the z axis is the resulting load (t) exerted by the press, which is obtained by adding the value of the 4 sensors, as seen in Fig.4. These working limits are provided by the manufacturer who sets the maximum distance for the centre of gravity to be displaced both in x and y for a certain tonnage carried out by the press, that is, the more load the press applies, the less tolerance of displacement of the GC by equipment safety. The press incorporates as standard a control process, so if the deviation goes outside the limits of the cone, the press will stop immediately. However, this behaviour does not prevent the failure. Fig.4 shows the cone provided by the manufacturer and the GCs obtained

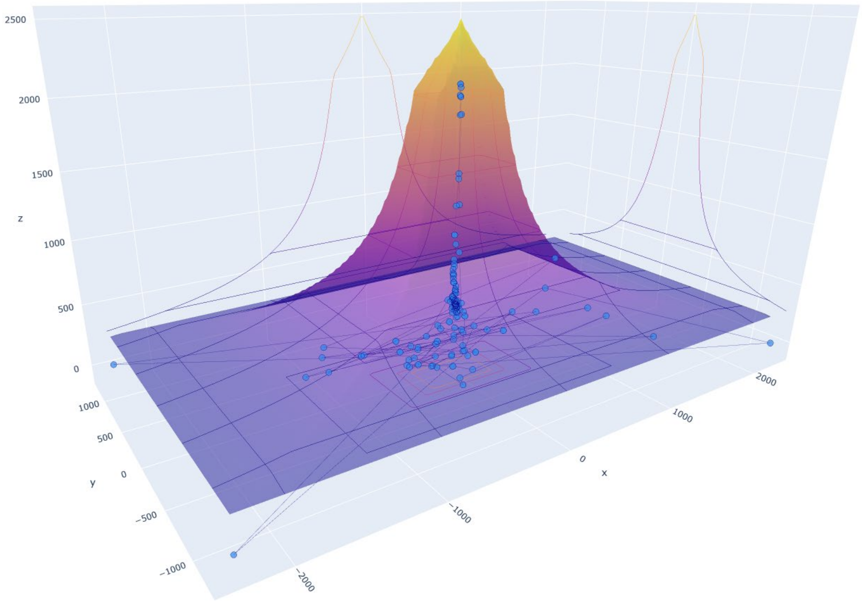


Fig. 4: Plot GC data in 3D

In order to analyse it in more detail and understand how the slide behaves, the result obtained in 2 dimensions is analysed, with a graph corresponding to the deviation (in mm) in the x-axis and another for the y-axis, which is how the test results carried out will be displayed. Next, Fig.5 shows the centre of gravity for an actual part produced.

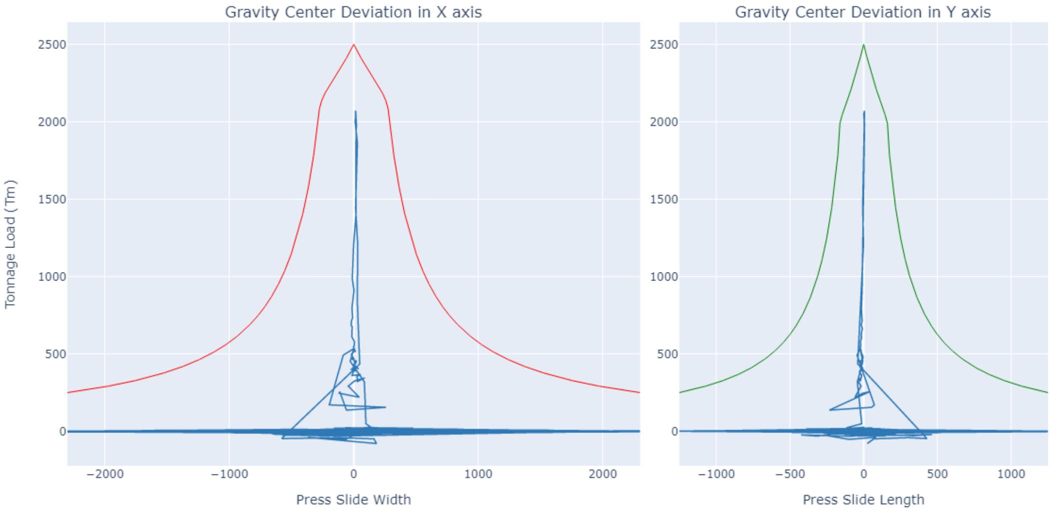


Fig. 5: Gravity Centre Data

In Fig.5 you can see how the load is centered and this is what we want to get for all the parts produced.

Developed Tool Calibration

In order to accurately determine the imbalance limits, we need to carry out a calibration process that allows us to determine, together with the maintenance engineers, the imbalance limits in which a maintenance order should be applied. The calibration process consists of carrying out different cycles of the press on steel columns specifically placed at the base of the press. These columns have to be initially at the same height. The gauges that allow us to control the degree of press imbalance are placed in the upper part.

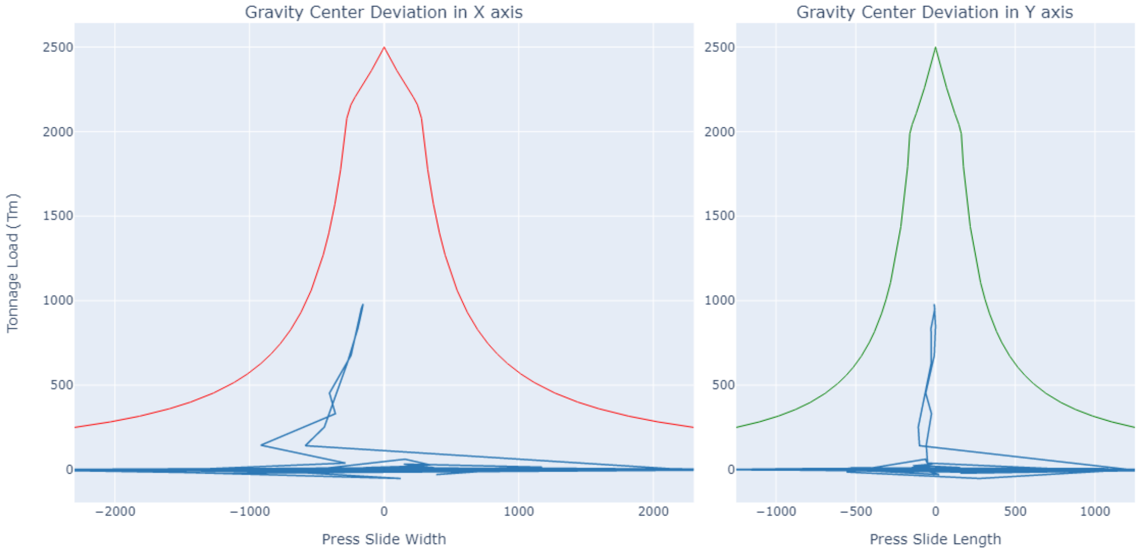
After adjusting the regulation of the press according to measuring a valid tonnage for the test without overloading the equipment, we validate that the height of the columns is the same, measuring several cycles with the tonnage centered on the developed tool. Once verified, the height in the different columns begins to be changed using calibrated gauges.

Fig. 6: Test measurement tools installation

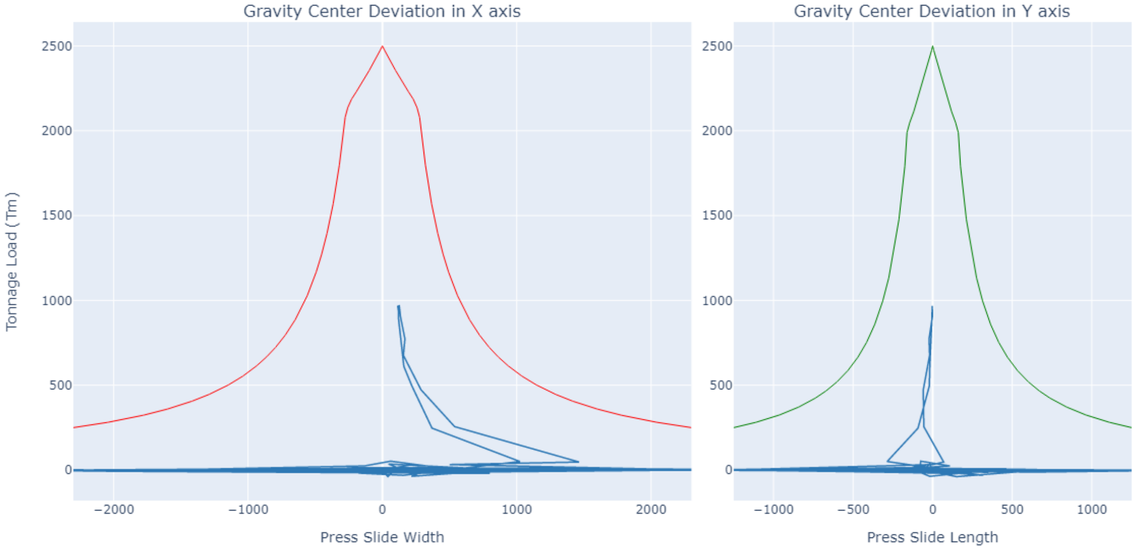
We perform tests by modifying the height of the different columns between them, using 1 and 2 mm thick gauges. These thicknesses have been selected by the maintenance engineers as the limit deviations in which the surveillance system should give a Warning alarm (1 mm deviation) and Red alarm (2 mm deviation)

Results

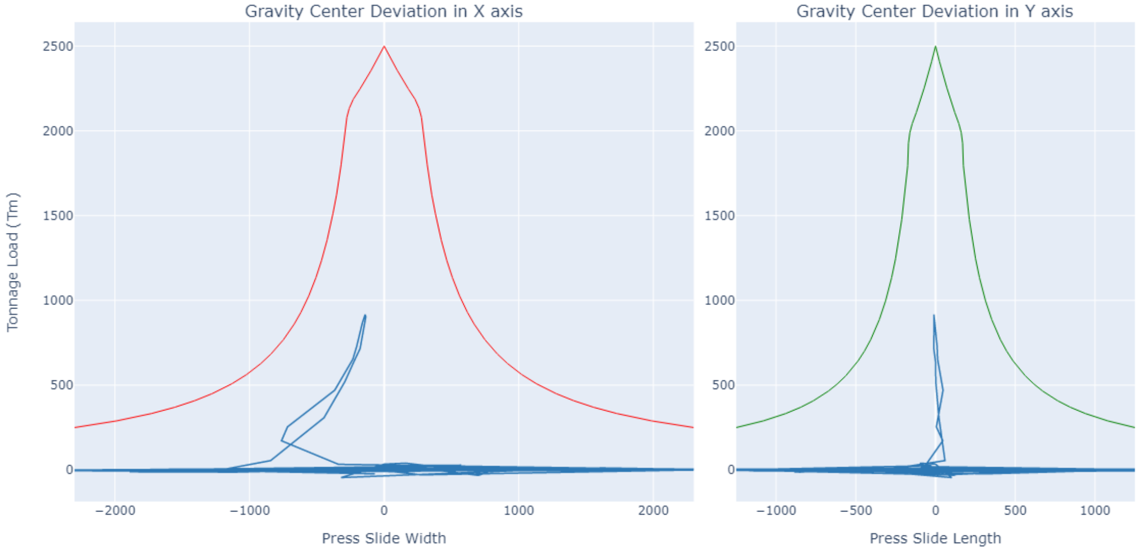
If we take the height of the columns without a sheet as a reference point, this being the initial height $h_0 = 0\,mm$, depending on the gauges distributed in the different columns, we will have heights between 0 and 2 mm. Next, the measurements obtained with the deviation of the gravity centre showed that one corner had a $h = 2\,mm$, the adjacent ones had a $h = 1\,mm$ and the opposite column diagonally had a $h = 0\,mm$. As seen in the pictures, on the axis x there is a clear deviation of the centre of gravity in the column where we have more unevenness, Fig.7.a and Fig.7.c where the 2 mm sheets were in the columns on the left, the front and rear respectively, all the measured points of the cycle are found in the left area of the graph, also with a distance from the centre of the coordinate axis that can be seen with the naked eye. In the case of axis deviation y, the deviation is not evident, this is because the distance between the front and rear rod feet is much smaller than the distance that separates these rod feet from left to right, therefore, the result obtained from the deviation of the gravity centre is not as large as in axis x. But if we observe the calculations obtained analytically, starting from the basis that the points appear on one side or the other of the axis to appreciate said deviation, in all the tests carried out, when the deviation was towards the front, on the axis y , all the calculated points had a negative sign during drawing and the same happened when the deviation was towards the rear, the calculated points had a positive sign during drawing. It is important to bear in mind that this only happens during the drawing, because at the lowest point of the press, the BDC, in some cases, has been either zero or appeared on the opposite side of the axis where the deviation is, such as the case of Fig.7.c on axis y. Therefore, although it is easier to identify it, we can ensure that we can find the deviation of the press between the front and rear area and be able to monitor this event automatically, so the deviation in this axis will be analyzed depending on the number of points we have to left or right of the standard work zone. The same result has been obtained when we have deviated the press slide giving more height to the columns on the right as we can see in Fig.7.b and Fig.7.d, where the variation of the gravity centre on axis x can be clearly seen but not so clearly seen on axis y, where the same result happens as in the case just explained at the time of finding the GC deviation between the front and rear of the press.



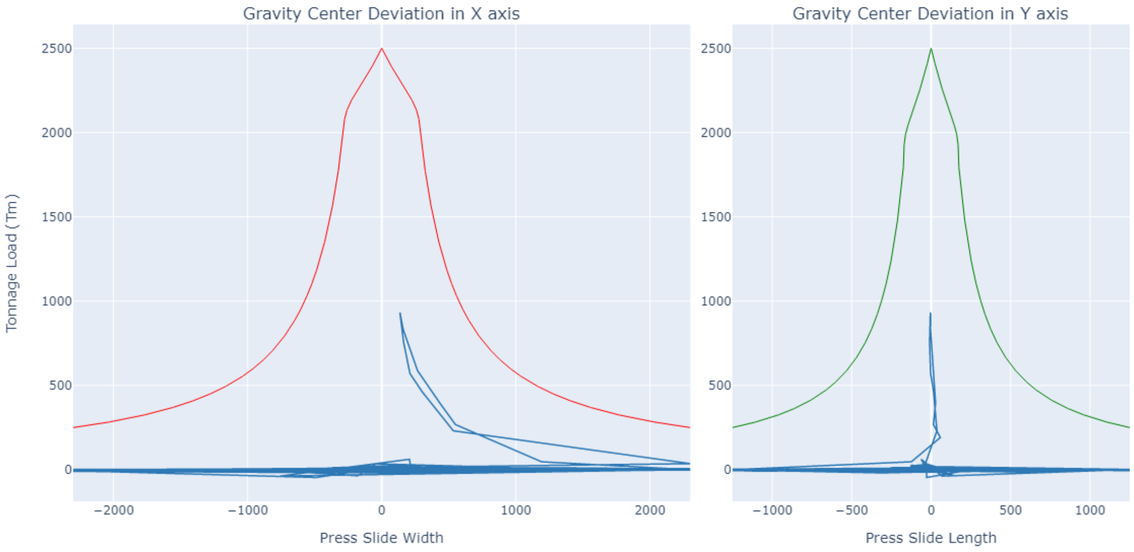
(a)



(b)



(c)



(d)

Fig. 7: Gravity Centre measurements with height difference of (a) 2 mm in front left column, (b) 2 mm in front right column, (c) 2mm in rear left column, (d) 2 mm in rear right column

In addition to the results shown in Fig.7, measurements were also made by deviating the two lateral columns, both on the left and on the right with a 1mm thickness difference between the two sides, these two measurements being satisfactory. This was also made for both the front columns and the rear ones. In this case, we can see the deviation graphically more clearly in Fig.8, in the same way in all measurements the points of the gravity centre measured were always on one side or the other of the axis y according to the height distribution in the columns, as we have seen in the results shown, the deviation in the axis y is not easy to see with the naked eye, but the calculated centre of gravity for each press position is always on the side of the axis where the imbalances appear.

Fig. 8: GC measurement with height difference of 1 mm in front columns

Conclusions

As it is shown, the developed tools work correctly, being able to measure the deviation of the centre of gravity very precisely with changes in thickness from 1 mm, obtaining information in a clear way to understand where exactly faults begin to appear in the press and how it is working in terms of press quality. Therefore, we can say that the developed monitoring tool is working as expected, detecting what is happening in the process in real time.

Next step would be to monitor the work of the press, define how it works for each of the different dies that are mounted on the line, since due to the geometry of each of the parts of the car chassis the measured centre of gravity is different between them, but it should always be the same for the same part. Therefore, once the normal working status is known for each one, together with the plant maintenance team, we should determine the working limits that can be considered critical to define an automatic alarm system. As soon as this variation of the GC is constantly repeated with regard to the work standard, we will be able to determine that we have a problem in the press, and it would be stopped in order to carry out a check of the different mechanical components. Also, this tool would be useful to detect changes in the product quality or identify if a defect has appeared. (Would be interesting to find out a correlation between the GC data when is not constantly repeated and the product quality.

Acknowledgments

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