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Robust control of the draw-in in a deep-drawing process: a measurement-based approach

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***Abstract* – A methodology to consider the process variability related to a deep-drawing process is proposed, with reference to specific laboratory conditions. In fact, the integration among numerical simulation, control system and measurements informative flows carried out in controlled conditions is expected to improve - and thus limit, the variability introduced in the conditions of the field, where the machining tool is called to operate. The results obtained from a preliminary experimental campaign aimed at fine-tuning the models and feedback control algorithms appear promising. This is based on the use of the laser triangulation technique to monitor displacement during the draw-in of the blank. A feasibility analysis and a consequent test plan are necessary to evaluate the system signature both in optimal conditions and to identify and implement the practical situations affecting the process (e.g. lubricant conditions and materials properties) in view of a technology transfer in the field. The methodological suggestions are envisaged to optimise the monitoring strategy, as well, to make the control robust and enhance the process sustainability and the product quality.**

Keywords – Deep drawing, Feedback control, Robustness, Measurement uncertainty, Displacement laser triangulation sensors.

I. INTRODUCTION

The deep drawing process is a sheet metal forming process, often adopted in the automotive industry. In this process the blank is formed into the die cavity by the mechanical action of the punch. A blank holder is introduced to regulate the draw-in of the blank. The action of the blank holder can prevent defects on the drawn component such as cracks, wrinkles and thinning [1-2]. Therefore, one of the design parameters affecting the drawing process is the force on the blank holder [3-4]. In fact, it has been shown that an increase in the force on the blank holder can lead to a reduction in wrinkles. However, this force should be optimized as an excessive increase could lead to splits in the thinnest areas [2].

The quality of the deep-drawn component, however, can also be affected by the process variability due, for example, to the lubrication conditions and to the properties of the material which can change depending on the supplier or the coil adopted [3]. Positioning of the blank is another noise parameter that could affect the quality of the final drawn component [5]. In order to optimize the process, press machines with active blank holders have recently been adopted in order to locally regulate the draw-in of the blank thanks, for example, to magneto-rheological actuators [6].

The goal of this research work is to develop a numerical-experimental methodology that allows for optimizing the deep drawing process to provide a robust control system with the necessary information to keep the process in optimal conditions.

II. METHODOLOGY

The innovative proposed methodology is schematized in Figure 1.

Specifically, a Finite Element (FE) model was first developed in AutoForm for simulating the investigated process to manufacture the component in Figure 2 in DC05 steel. Numerical simulations allow to evaluate how the design parameter (force on the blank holder) and the noise variables (friction coefficient and yield stress of the material) affect the quality of the final component.

The quality of the drawn component was evaluated by considering the percentage of area with defects such as splits, thickening, compression and insufficient stretch.

To obtain a reliable prediction of the process, the FE model was calibrated by means of preliminary experimental tests carried out with the 3000 kN hydraulic press machine designed by Gigant Company (Italy).

A multi-objective optimization of the process was then performed through the Desirability Function Approach (DFA). This phase allows to identify the optimal force on the blank holder, i.e. the optimal draw-in of the blank is able to guarantee a final drawn component free from defects. The idea is the development of a control strategy able to modify on-line, in the presence of the process variability, the force on the blank holder in order to restore the draw-in of the blank to the optimal value. To monitor online the draw-in of the blank, laser triangulation sensors were chosen [3], [4], [7-10].

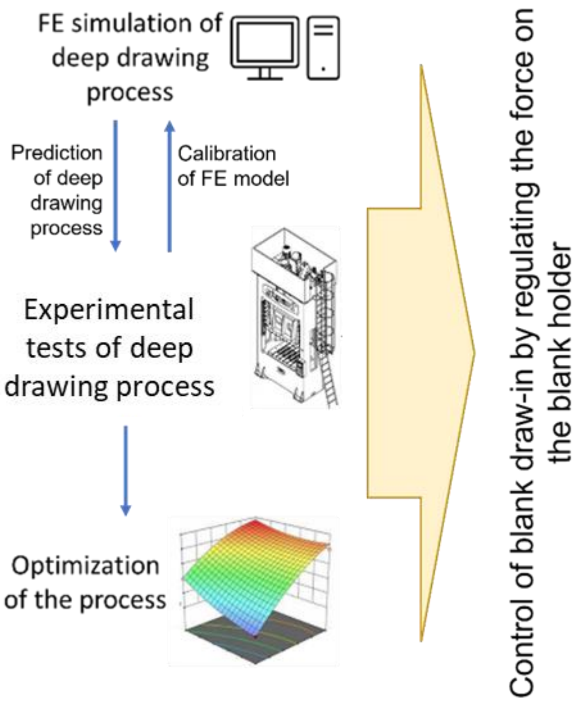

Fig. 1. Graphical abstract of the proposed methodology

Once the FE model was calibrated and the optimal design condition found, the experimental campaign on the hydraulic press machine aims at: (i) comparing the experimental results with the numerical ones and (ii) identifying the variability band attributed to the optimal draw-in profile of the blank.

This is expected to provide a strong support to develop the feedback control system, since a correct value of the difference between the measured draw-in and the desired optimal one should be established beyond which the force on the blank holder needs to be modified.

III. PRELIMINARY RESULTS AND FUTURE DEVELOPMENTS

By adopting the multi-object optimization on FE data, minimizing percentages of the area with defects, the optimal solution was identified. This solution requires a force on the blank holder equal to 550 kN.

In correspondence with the identified optimal solution, the profiles of the draw-in of the blank were provided numerically at the points identified in Figure 2. As an example, Figure 3 gives the draw-in of the blank during the process, with reference to point B.

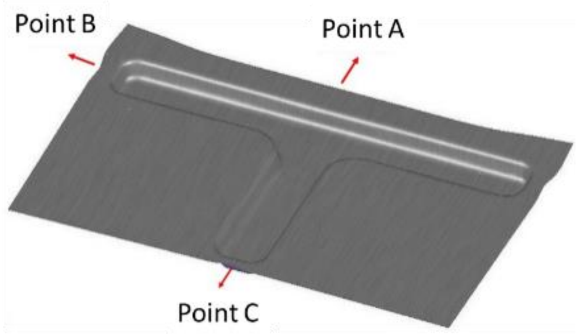

Fig. 2. T-joint geometry with points where the draw-in is measured

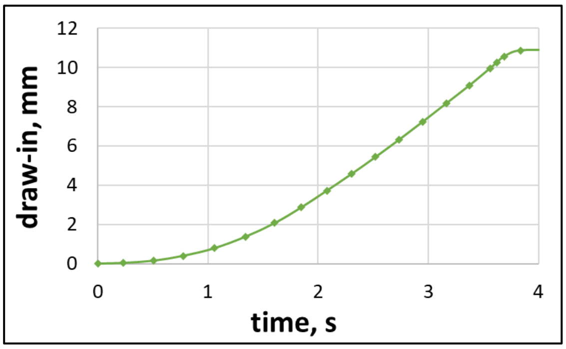

Fig. 3. Draw-in behavior from numerical simulation.

By carrying out preliminary tests on the press hydraulic machine, a good agreement was observed between the numerical and experimental results. Figure 4 shows the numerical-experimental comparison of the profile of the drawn component under optimal conditions and Figure 5 shows the difference between the numerical and experimental values of the draw-in measured at point B, over the process time needed for a single drawn component.

Fig. 4. Numerical-experimental comparison profile of the drawn component under optimal condition.

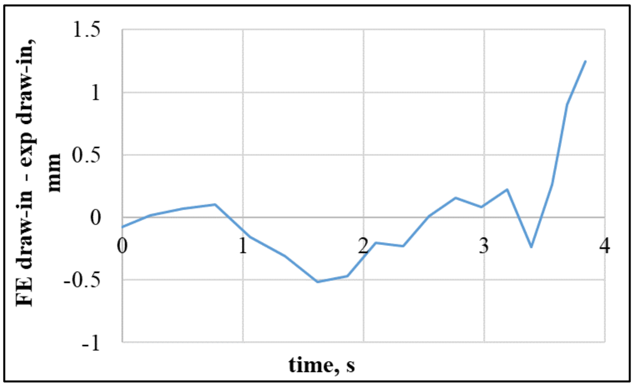

Fig. 5. Numerical and experimental comparison in the draw-in of one blank.

In order to verify the values taken as a reference for the optimization of the deep drawing process, we intend to metrologically characterize the drawing process in operating conditions. In fact, the process stability and repeatability are recognized as *sine qua non* characteristics for the control system effectiveness, and for a reproducible and automated adaptation of the process [11]. The stamped product is also expected to benefit from this preliminary assessment of the process behavior.

To this aim, the process variability has to be analyzed to verify the correct setting of the control parameters. This pertains to the extension of the test campaign in repeatability conditions [12] (i.e. studying the behavior of a larger batch of drawn components, holding the same process parameters) and by carrying out tests by varying the most influencing and disturbance parameters that can be controlled. In particular, the measurements obtained from the repeatability procedure will be used to define the signature of the process, [13], [14], and the variability of the optimal drawing process. Measurements obtained by introducing noise conditions to process, keeping the variability related to other boundary conditions negligible, define the influence of the disturbance parameter on the variability of the process.

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