Sensitivity Analysis of Deep Drawing Process Control Parameters

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Abstract

The problem of sheet metal stamping in general was analyzed, defining the parameters involved and the objectives to be reached for process optimization.
D.O.E. (Design of experiments) and statistical analysis (ANOM, ANOVA) techniques were applied to the case of a component which, though of geometrically simple configuration, was representative of the process.
The objective of the work was methodological: through this application, it was possible to develop a series of procedures and obtain positive initial results, particularly as regards sensitivity analysis for the parameters involved.

Riassunto

Si è analizzato il problema dello stampaggio di lamiere in generale, definendo i parametri interessati e gli obiettivi da raggiungere per una vera ottimizzazione del processo.
Si sono applicate le tecniche D.O.E. (Design of Experiments) e di analisi statistica (ANOM, ANOVA) allo studio dell'imbutitura di un componente che, anche se di semplice forma geometrica, fosse rappresentativo del processo stesso.
Lo scopo principale del lavoro è stato metodologico: attraverso questa applicazione si sono potute sviluppare alcune procedure applicabili anche ad altri casi e ottenere al contempo una prima serie di risultati positivi, particolarmente riguardo all'analisi di sensitività dei parametri considerati.

Introduction

In mass production of thin sheet automotive body panels, optimizing the stamping process is of vital importance in order to produce high quality, defect-free components and to contain costs by eliminating rejects, re-work and deviations from the planned process cycle.

Before passing to full-scale production stamping for a given panel component, considerable attention is devoted to fine-tuning the various operations which make up the stamping cycle. Of these operations, deep drawing is the most critical, as the complex panel forms involved require severe sheet metal deformation conditions [1].

Fine-tuning the automotive body panel drawing operation is difficult because of the multitude of factors which influence it, the interaction between these factors, and the general interdependence between different areas of the stamping during the process. This difficulty is further compounded by quality requirements for the finished part, which are often mutually exclusive, and must in any case be satisfied on the entire effective finished configuration of the stamping.

It is thus strategically important to develop models and methods which make it possible to deal with the problems encountered in this process systematically and completely, with the objective of coming as close as possible to process optimization [2].

In this way, an attempt is made to go beyond the current approach to the problem, which is based on the experience, knowledge and intuition of specialist in the field, and thus difficult to impart to non-specialists or transfer to other applications.

In this context, the first important step is to describe the problem correctly in terms of the objectives, variables and roles involved: here, the first stage consists of sensitivity analysis of the relative importance of each factor, culminating in process optimization as such.

It is also important to note that the developments made in hardware, software and mathematical modelling techniques in recent years, together with those which can reasonably be expected for the near future, now make it possible to simulate the stamping process in many real cases [3], thus making it less costly and time consuming to analyze a large number of situations and combinations of variables, without necessarily using prototypes. This type of capability is the prerequisite for any real optimization.

This paper, however, does not propose to consider these aspects in detail. Rather, our aims are to discuss the methods needed to define a process design model through the organized and systematic planning of the situations to be examined, i.e. design of experiments, then to analyze the results independently of whether they were obtained experimentally or through numerical modelling, and finally to identify areas of feasibility and optimal solutions.

Process design model

To develope a workable process design model, it is first necessary to identify the variables affecting the process: generally, they are factors which can be divided into controllable factors and noise factore [4].

Controllable factors are those which can be specified at the design stage, or which can be modified or programmed during production. The major controllable factors are listed in Table 1.

TABLE 1 - Drawing process: main "CONTROL FACTORS"

Geometry of die components:	Punch Drawing Die Bottom Die Blankholder Beads
Blanck configuration and position on the die	
Type of sheet steel	
Lubricated sheet/die contact: It depends on:	– Die Material and Finishing – Sheet Surface Condition – Type of Lubricant – Lubricant Distribution over Sheet and Die
Stamping velocity and motion pattern	
Die alignement conditions	

These factors can in turn be divided into two subgroups in relation to the costs involved in working with them: Control factors if the costs are low and Tolerance factors if they are not. This distinction can be used in identifying the best cost/benefit trade-off.

Noise factors are either random, noncontrollable process factors, or deviations of process parameters from predetermined values. A list of the most important noise factors is shown in Table 2.

TABLE 2 - Drawing process: main "NOISE FACTORS"

Stamping temperature	
Die condition as result of:	Wear Repair Modifications
Press slideway wear and clearance	
Effective quality of sheet on lubricant It may deviate from specifications as a result of variations in supply	
Effective machine parameters:	Blankholder force clearance Stamping velocity
They may deviate from set parameters as a result of machine control irregularities	

Next, it is necessary to clearly identify the real objectives of the design, viz. the quality of the results which must be achieved, which is defined as the correspondence between certain quality functions and the acceptance standards. These functions are outlined in Table 3.

TABLE 3 - Drawing process: main "QUALITY FUNCTIONS"

Absence of cracks and puckering Absence of wrinkles, waving, buckling Production of desired workpiece configuration Absence of necking Absence of pits Absence of protective layer abrasion Small level of residual stresses Constant workpiece thickness Sufficient level of deformation
Quality functions priorities must be defined depending on component to be stamped

Once the design variables and objectives have been defined in this way, a multitude of possible methods can be used. Essentially, these methods can be grouped into two large families:

- Methods in which the design is approached sequentially, analyzing a first solution, using the results to identify a better solution, and so on until the optimum solution is reached.
- Methods in which a certain number of situations are planned a priori and all results are analyzed together using statistical techniques to identify the optimum solution.

For particularly complex problems, research procedures can be organized in which the methods described above are alternated and integrated.

In all cases, a sensitivity analysis stage is involved, which is often in itself decisive for an understanding of the problems and their solutions.

Design of experiments

Design of experiments involves identifying the control parameters which should be modified in order to arrive at an optimal solution, and then specifying the values which these parameters can assume.

The basic criteria to be borne in mind are as follows:

- The area containing the optimal solution should be identified by performing as few experiments as possible.
- It is necessary to identify a stamping condition in which stamped components continue to satisfy objectives even in the presence of noise factors.

One way of proceeding is based on performing experiments according to complete or reduced factorial plans. This was the method used for the case described herein.

Results were then analyzed through statistical techniques, ANOM and ANOVA in particular, using the SAS system [5, 6].

Application

Applicability of the methods indicated above was verified through a study of the drawing process used for a mass-production component of simple configuration for which extensive processing data were available, viz. an axially symmetric cup.

Stages of the workpiece drawing process on a hydraulic press are illustrated in fig. 1.

Figure 2 shows the most important process parameters.

Figure 3 shows the range of parameters taken into consideration for the experiment.

Figure 4 shows the quality functions established for the application in question and the associated targets.

The factorial plan and a list of the control variables considered are shown in figure 5 together with the corresponding stampings.

Mean results of analysis are shown graphically in figure 6. As will be seen, the significant parameters in the application concerned include blank dimensions and, to a lesser extent, the lubricant.

The double curve in figure 7 shows critical rupture and flange starving levels blank diameter. Such a curve makes it possible to identify the feasibility range (going from approximately 234 mm to 253 mm) in which stamping satisfies quality targets.

Conclusions

The application described here in resulted in an increased knowledge of the sheet metal stamping process and made it possible to assess the utility of D.O.E. and statistical analysis techniques in improving this process.

At the time of writing, the parameter sensitivity analysis stage had been completed, allowing us to clearly identify the feasible design range and providing a solid foundation for subsequent optimization. The results achieved to date have been encouraging and lead us to conclude that it is both possible and advisable to continue along this route, extending the methods developed to other cases of industrial interest.

References

[1] F. Mazzoleni. Tecnologie dei Metalli - Volume terzo, *Lavorazione delle lamiere, saldatura, trattamenti termici*, UTET, Torino 1980.

[2] Metal Handbook. Ninth Edition - Vol. 14, *Forming and Forging 1988*, ASM International, Metal Park, Ohio 44073.

[3] A. Cella, M. Guida, A. Messina, F. Panico, G.L. Raffetto, P.P. Strona. *3D F.E.M. Analysis of Sheet Metal Forming Problem IDDRG*, Congress Proceedings, Borlange, Sweden, 1990.

[4] P.P. Strona. *Parameter Design methods applied to problems of design in Automotive Industry*, ATA, n. 4, April 1990.

[5] SAS Institute Inc. SAS/STAT. *Guide for personal Computers*, Vers. 6 ed. 1987.

[6] G.E.P. Box, W.G. Hunter, J.S. Hunter. *Statistics for Experimenters*, Wiley, 1978.

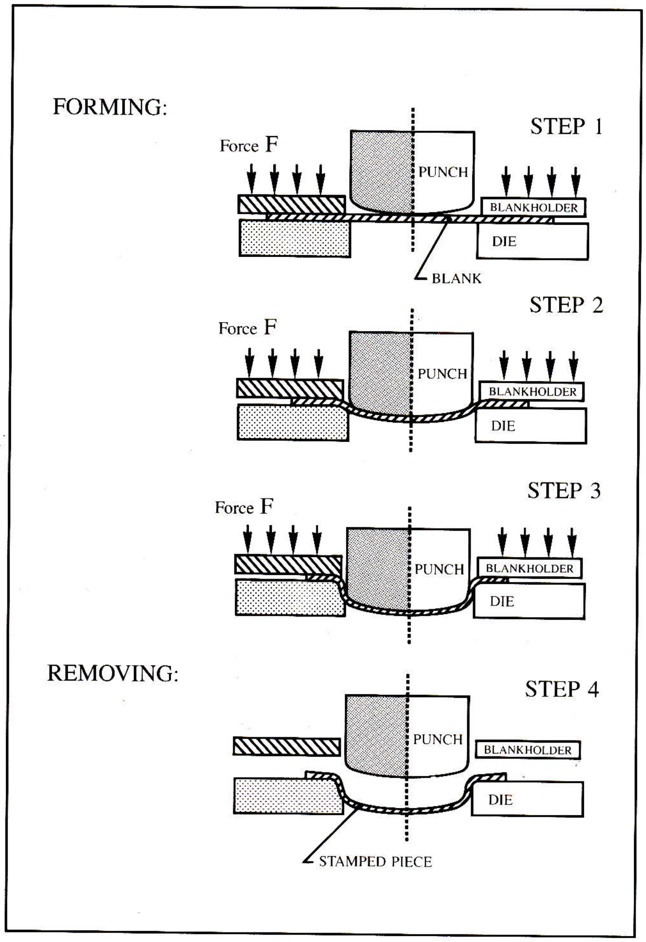


Fig. 1: Deep drawing process using hydraulic press.

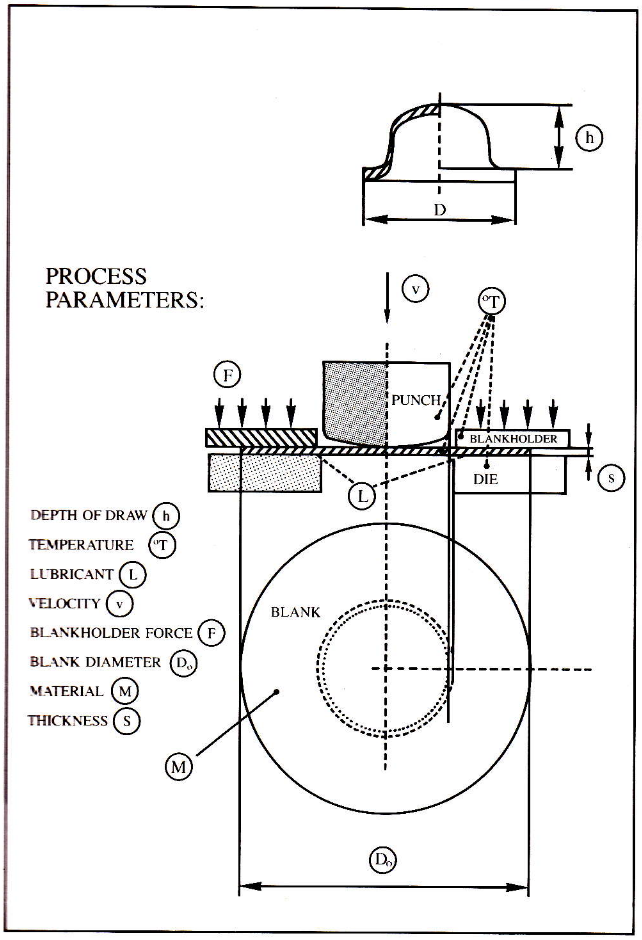
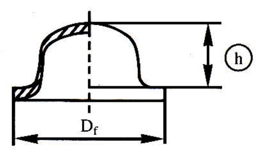


Fig. 2:
Parameters design. Deep drawing of Axi-Simmetric cup (partially spheric punch).

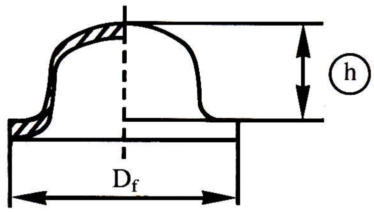


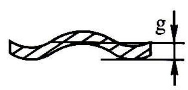
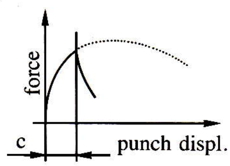
PARAMETERS RANGE:

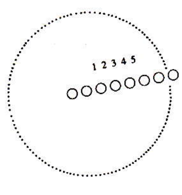
	min.	mean	max.
TEMPERATURE (DEGREES °C)	ambient (~26)		
LUBRICANT (Oil Draw Ind %)	protect. (3,5)	prelube (30)	imbutex (40)
(Velocity mm/s) FLOW RATE l/min	(~14) 20	(~38) 100	(~59) 180
(Blankh force kN) RAM PRESS. Bar	(~50) 20	(~70) 40	(~120) 60
(Area cm^2) DIAMETER mm	(415) 230	(490) 250	(572) 270
MATERIAL (Yield P. N/mm^2)	FeP04 (~175)		
THICKNESS mm			1,54

Fig. 3:
Parameters design. Deep drawing of Axi-Simmetric cup (partially spheric punch).

QUALITY FUNCTIONS:



GENERAL SHAPE	constant height h = 65 mm target useful diameter $_fD \geq 180$ mm	
WRINKLES	target: no wrinkles measure: if wrinkle occurs No. and height g	
CRACKS	target: no crack measure: if crack occurs punch displacemenc before the crack	 
LOCAL STRAINS	measure: crack criticity target: the lowest local planar strains level	



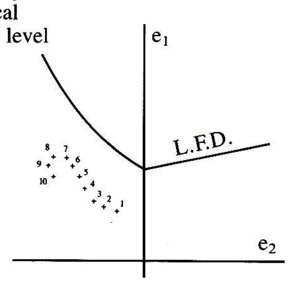


Fig. 4: Parameters design. Deep drawing of Axi-Simmetric cup (partially spheric punch).

PARAMETRS SETS: (full factorial design 24)

test n.	oil	main slide velocity mm/sec.	blankholder force kN	blank diameter mm.
1	drawing	14	50	230
2	drawing	14	50	270
3	drawing	14	120	230
4	drawing	14	120	270
5	drawing	59	50	230
6	drawing	59	50	270
7	drawing	59	120	230
8	drawing	59	120	270
9	protective	14	50	230
10	protective	14	50	270
11	protective	14	120	230
12	protective	14	120	270
13	protective	59	50	230
14	protective	59	50	270
15	protective	59	120	230
16	protective	59	120	270

other process parameters: depth of draw h = 65 mm
temperature T = ambient
material M = FeP04
thickness s = 1,5 mm

PRELIMINARY DRAWING EXPERIMENTS

Fig. 5: Parameters design. Preliminary drawing experiments.

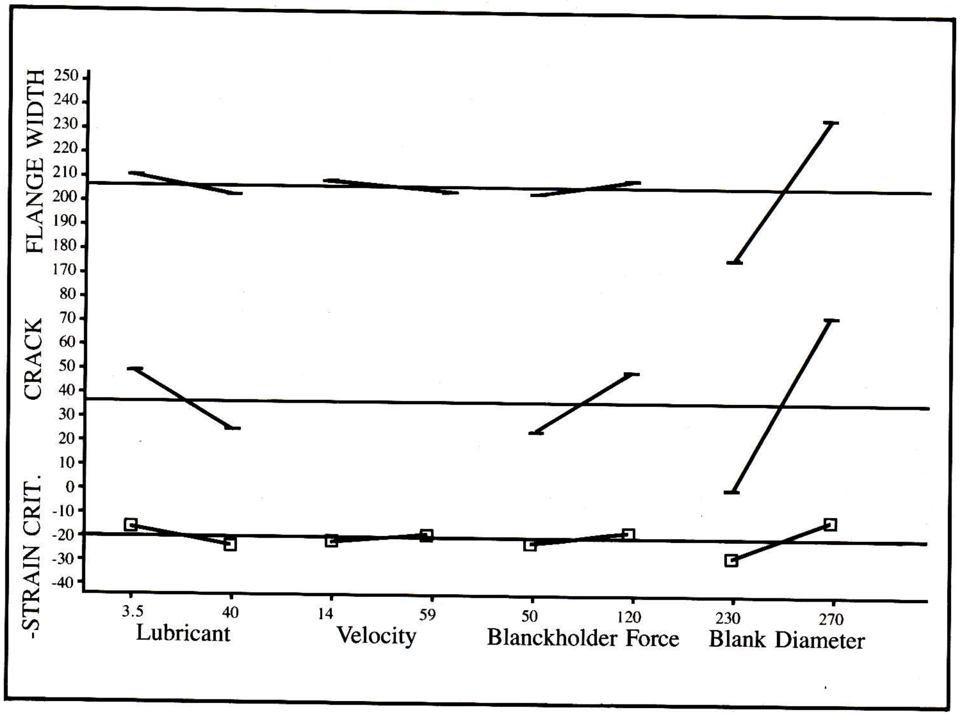


Fig. 6: Deep drawing of Axi-Simmetric cup. Analysis of Means.

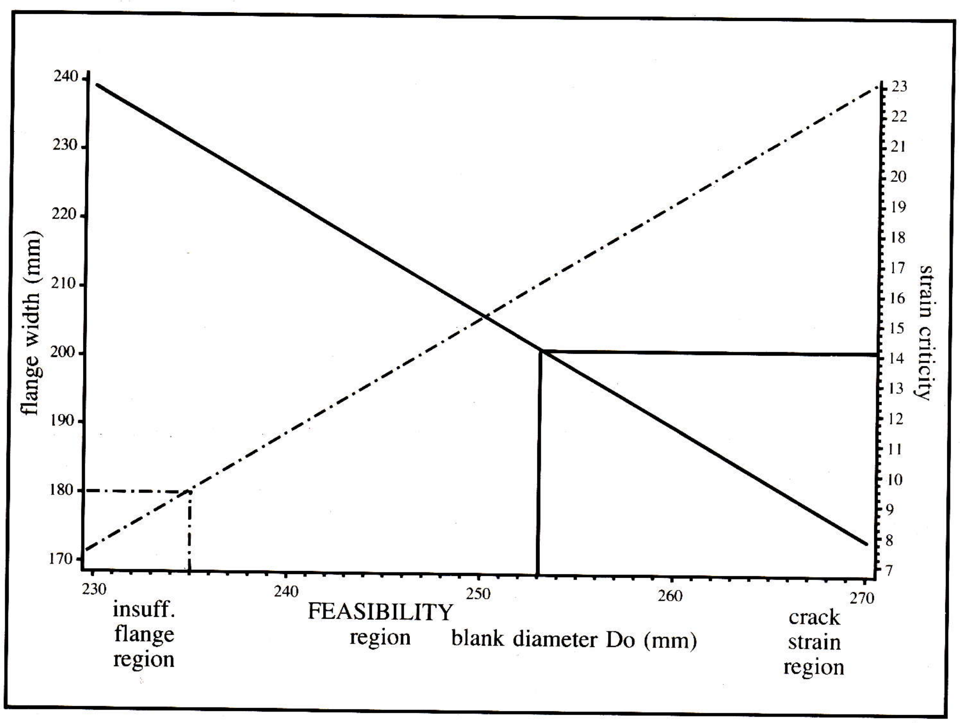


Fig. 7: Deep drawing of Axi-Simmetric cup. Blank diameter optimization.