Transactions of the VŠB – Technical University of Ostrava, Mechanical Series
No. 2, 2010, vol. LVI
article No. 1780

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SPRING-BACK ANALYSIS OF STAMPING FINAL SHAPE IN THE AUTOFORM 4.06 AND PAM-STAMP 2G ™ PROGRAMMES AND COMPARISON WITH DIMENSIONS SPECIFIED AT PART PRODUCTION DRAWING

ANALÝZA ODPRUŽENÍ KONEČNÉHO TVARU VÝTAŽKU V PROGRAMU AUTOFORM 4.06 A PAM-STAMP 2G ™ A POROVNÁNÍ S ROZMĚRY PŘEDEPSANÝMI NA VÝROBNÍM VÝKRESU SOUČÁSTI

Abstract

The contribution concerns the drawing process simulation of intricate asymmetric shape stamping from thin sheet-metal – inside reinforcement of the car front door, with aiming at spring-back evaluation of this stamping after drawing operation. The evaluation of simulations results with the use of AutoForm 4.06 and PAM-STAMP 2G ™ programmes is carried out – the evaluation of utilization of the material plasticity stock and risk of stamping crack at drawing, the sheet-metal thinning at drawing, the wrinkling of the stamping at forming. Then the procedure of spring-back simulation after stamping drawing is described. The results got by simulations in both programmes are compared partly to each other, partly with dimensions of real stamping got by drawing and consequently by 3D measurement of stamping.

Abstrakt

Článek se týká simulace procesu tažení výtažku nepravidelného tvaru z tenkého plechu – vnitřní výztuhy předních dveří automobilu, se zaměřením se na vyhodnocení odpružení tohoto výtažku po operaci tažení. Je provedeno vyhodnocení výsledků simulací pomocí programů AutoForm 4.06 a PAM-STAMP 2G ™ – vyhodnocení využití zásoby plasticity materiálu a rizika porušení výtažku při tažení, ztenčení plechu při tažení, zvlnění výtažku při tváření. Dále je popsána simulace odpružení po tažení výtažku. Výsledky simulací získané oběma programy jsou porovnány jednak vzájemně, jednak s rozměry skutečného výtažku získanými tažením a následným 3D měřením výtažku.

INTRODUCTION

The tuning of the critical dimensions of the tool for the asymmetric shape intricate stampings production in order to keep to the stamping dimensions and tolerations specified at part production drawing is a lengthy process, but necessary in practice. It concerns especially the shape deviations which appear after drawing of stamping and which are different from required stamping shape, i. e. material spring-back after drawing process. The spring-back, by another name return of material in direction to original shape before plastic deformation, for given material depends on material thickness, drawing gap and drawing radius, a yield stress and a level of material hardening. Degree of the spring-back can be revised by several ways – for example by increasing of yield stress, by maximiza-

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tion of drawing gap and drawing radius and by decreasing of material thickness the spring-back increases. The minimal value of spring-back will be achieved with the rate of material thickness to drawing radius bigger then 0,4.

According to the intricacy of this process it is suitable to use the software on a base of finite elements methods (FEM). Thanks to the most modern technologies like PC simulations it is possible to cut the time of tools preparation, mainly in development offices, where the softwares simulating the forming process with the use of finite elements methods (FEM) are used standardly in these days. Principle of the FEM consists in distributing (discretization) of the connected body (stamping) into specific (finite) number of elements, whereas the ascertained parameters and calculations are determined in single nodal points. The final elements must be defined so that the behaviour of element is described enough. So individual elements need not be small necessarily, it depends on a case of described system. It is valid that with increasing of elements number into which the stamping is distributed the number of nodes increases too and thereby accuracy and objectivity of result are increasing too. Requirements on capability and computer technology output increase too, of course.

For making the stamping model in this contribution the software CATIA V5R16, which is developed by Dassault Systems Company, was used. Many programmes exist on base of finite elements method (FEM). For calculations and simulation of stamping drawing the software AutoForm 4.06 and PAM-STAMP 2G ™ was used.

1 INSIDE REINFORCEMENT OF THE CAR FRONT DOOR

An intricate shape stamping of reinforcement of car front door (see Fig. 1) from electrolytic zinc-coated sheet-metal suitable for drawing (see Tab. 1) was chosen for spring-back analysis.

Fig. 1 Inside reinforcement of the car front door

The stamping is A side post for a new type of car. So this stamping holds the roof, the front window and the mirror of the car, a high demands are put on the material and the design of part from point of view of a safeness. The material must fulfil definite required hardness and at the same time the drawability. Every nearer specification, which announces the location, the way of installation and more detailed description and effect of reinforcement are secret generally because of competition and mutual rivalry of car companies. That is why it goes from electronic resemblance CAT Part of chosen shape stamping, from required material properties and productive documentation, e. g. production drawing of the stamping. It is necessary to define drawing tools for the simulation in software described later, so 3D model of stamping must contain part for blankholder and draw beads. Used draw beads were evaluated as the most suitable for drawing of this stamping (see 4).

For production of car reinforcement the zinc-coated sheet-metal with thickness 1,1 mm and marked HC450X (equivalent H450+ZE) is required by the customer. Properties of this steel are given by norm ČSN EN 10346 (420110) with name: Continuously hot-dip coated steel flat products – Technical delivery conditions for material thicknesses from 0,35 mm to 3 mm. Mechanical properties of this material (see Tab. 1) respond to requirements on safeness of a crew of car in car industry.

Tab. 1 Mechanical properties of steel HC450X in sheet-metal form with thickness of 1,1 mm according to ČSN EN 10346

Thickness (mm)	Yield point in tension $R_{p\,0,2}$ (MPa)	Tensile strength R_m (MPa)	Ductility A_{80} (%)
1,1	450 ÷ 560	780 ÷ 900	15

2 STAMPING DRAWING PROCESS SIMULATION

Drawing process simulation of chosen intricate shape stamping was made in software AutoForm 4.06 and PAM-STAMP 2G ™ which belong to computational programmes based and worked on base of finite elements method (FEM). It is necessary to define many input drawing parameters which are described in following paragraph.

Software works with 3D model of stamping and blank, computational network of blank is generated in graphics pre-process setting with necessary boundary conditions of solution. Size and shape of individual elements are predefined in basic configuration and they can be changed as need, if the simulation results must be more exact. Definition of material properties is a next step, which must be done before start of calculation. Selection is done from material database, or a material can be filled manually according to tests results. From material database in software the material HC450X was chosen (see 2), mechanical properties of which were certified by appropriate tests and data were delivered right from car factory. After discretization of stamping surfaces to finite element network the position of tools in drawing process must be assigned to individual surfaces. All surfaces were created in software CATIA V5 from chosen stamping in integral system of coordinates, so their following instituting in face of itself for axis centering falls out.

3 DRAW BEADS DEFINITION IN SOFTWARE AUTOFORM 4.06 AND FOLLOWING DRAWING PROCESS SIMULATION

At stampings with intricate shape surfaces it is necessary to brake locally the sheet-metal for equal and symmetric forming. Creation of wrinkling, cracking and other defects appearing in drawing process of intricate shape stampings can be removed by using of the draw beads. The draw beads, their shape and breaking force, are important boundary condition, which must be defined in software and final shape of stamping is depends on it.

A few variations of draw beads were proposed (see Fig. 2) wherw the draw bead geometry stayed the same for all of variations, only values of braking force of blankholder and draw beads were changed. The draw bead has its specific geometry, which three times changes its cross section along the length (see Fig. 3 and Tab. 2). By that the braking force is regulated in three different areas of stamping. The drawing process simulation was made for every variation with values of forces from Tab. 3 and then the evaluation of results was made (see Tab. 4). The simulation result with the most suitable draw beads is in Fig. 4.

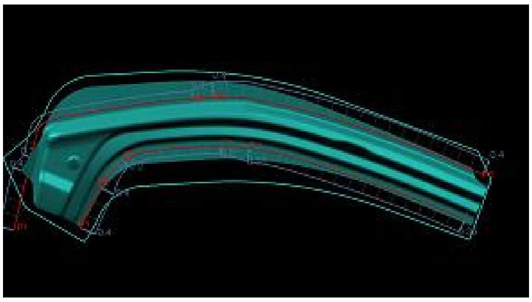

Fig. 2 Variations of draw beads, while braking force and force of blankholder were changed

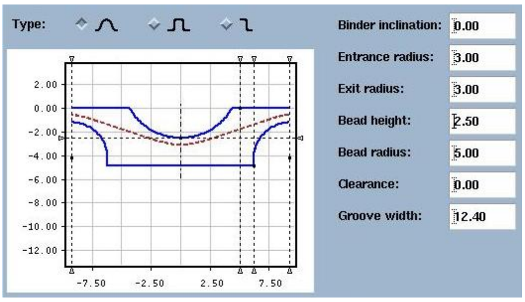

Fig. 3 Geometry of the first section of draw bead

The dimensions of groove for draw bead and radius are the same for all three sections of draw bead, on the length of draw bead (thought from the left to the right as Fig. 2) only the bead height changes. This shape and location of draw beads was used for all spring-back simulations in both softwares. The first section of geometry of the draw beads is seen at Fig. 3, the draw bead dimensions which are divided to three sections along their length, are shown in the next Tab. 2.

Tab. 2 Dimensions of the draw beads

Set up values	1st section of the bead	2nd section of the bead	3rd section of the bead
Binder inclination (mm)	0,0	0,0	0,0
Entrance radius (mm)	3,0	3,0	3,0
Exit radius (mm)	3,0	3,0	3,0
Bead height (mm)	2,5	5,0	4,5
Bead radius (mm)	5,0	5,0	5,0
Clearance (mm)	0,0	0,0	0,0
Groove width (mm)	12,4	12,4	12,4

Tab. 3 Four variations of set up values of braking force and blankholder force

Set up values	Variation 1	Variation 2	Variation 3	Variation 4
Braking force (kN)	5200	2000	4500	5200
Blankholder force (kN)	1350	1000	1350	1350

Getting information about drawing process is the result of drawing simulation of stamping from sheet-metal – drawability of the stamping, utilization of plasticity stock (i. e. risk degree of stamping cracking), sheet-metal thinning, arising of wrinkling (Tab. 4). These properties are a deciding factor which influences whole quality of stamping, its usage and operating life. By simulations of drawing in software AutoForm 4.06 it was found out, that the variation 2 of draw beads is the most suitable for drawing of the inside reinforcement of the car front door

Tab. 4 Drawing process simulation results at application of four variations of draw beat forces

Analysis	Variation 1	Variation 2	Variation 3	Variation 4
Drawability (-)	OK	OK	High risk of cracking	Risk of cracking
Utilization of plasticity stock (-)	0,760	0,787	1,010	0,830
Thinning (%)	26,0	19,9	28,0	21,0
Wrinkling (-)	0,02	0,01	0,02	0,02

The analysis of stamping drawability shows the deformations of chosen stamping. The endeavour is attainment to the highest amount of deformation at stamping while compliance the others conditions of simulation (low values of stamping crack risk, sheet-metal thinning and appearance of wrinkling). Deformed edge of stamping means the smaller probability of spring-back. According to Fig. 4, which shows this analysis, nearly whole body of the stamping is in safe (green) area. The biggest deviations from the safe deformation are in areas of compression "*Compress*" (blue area) and cramming "*Thicking*" (purple area) of material.

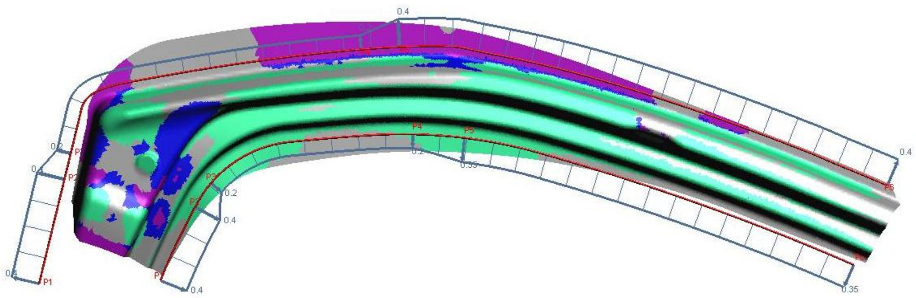

Fig. 4 Analysis of drawability of inside reinforcement of the car front door stamping in AutoForm 4.06 software

The analysis of stamping crack risk is given by numeric value, which represents the highest utilization of plasticity stock (i. e. the highest degree of deformation) at the stamping. If this result gets to value 1, it means that the deformation lies on the limit deformation curve in forming limit diagram of used sheet-metal and the cracking appears at the stamping.

The result of the sheet-metal thinning analysis is value, which says, how much is the sheet-metal thinned or crammed in percents at drawing of stamping. The limit value is the thinning in range 20 % to 30 % – the drawing process must be reviewed, thinning over 30 % is wholly unsuitable.

Local cramming of material generates the wrinkling of the stamping. Binder and using of draw beads hinder to this effect partly. Allowable values of wrinkling coefficient are: for wrinkling on straight surfaces – max. 0,03 (-), for wrinkling on curved, inclined and inflexed surfaces – max. 0,05 (-).

4 DRAWING PROCESS SIMULATION IN PAM-STAMP 2G ™ SOFTWARE AND COMPARISON OF SIMULATION RESULTS FROM THE BOTH PROGRAMMES

Drawing process of the stamping was simulated in PAM-STAMP 2G ™ software, where the same input parameters were set, like for drawing simulation in AutoForm 4.06 software (see 4). The analysis of stamping drawability with the use of forming limit diagram of used sheet-metal carried out in PAM-STAMP 2G ™ software is shown on Fig. 5. It is seen that no element of computational network gets to limit curve, so no cracks will appear at the stamping during the drawing.

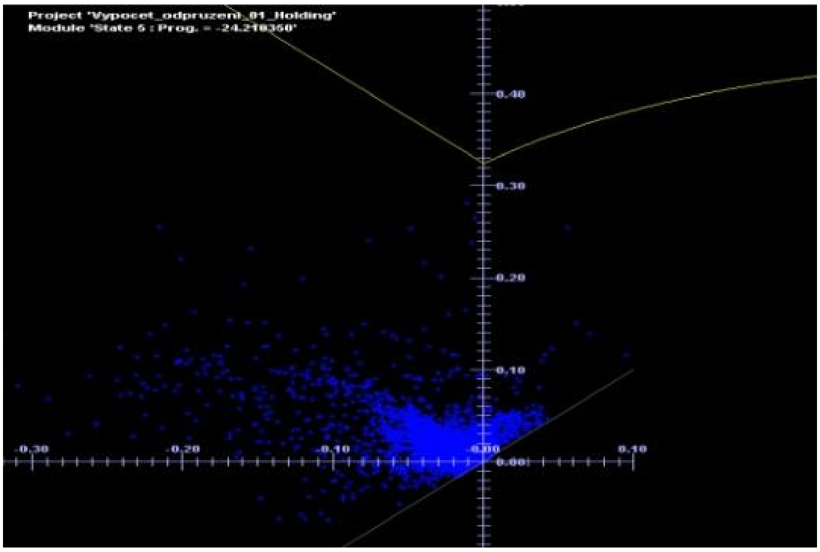

Fig. 5 Forming limit diagram with curve of limiting deformations of steel HC450X and with nodes representing elements of the tested stamping in PAM-STAMP 2G ™ software

The results of stamping drawing process in AutoForm 4.06 (see 4) and PAM-STAMP 2G ™ (see 5) programmes are arranged into the table for possibility of comparing. The analyses of drawability of the stamping, utilization of plasticity stock (i. e. risk degree of stamping cracking), sheet-metal thinning, arising of wrinkling were used for results comparison (tab. 5).

Tab. 5 Comparison of drawing process simulation results in AutoForm 4.06 and PAM-STAMP 2G ™ programmes

Analysis	AutoForm 4.06	PAM-STAMP 2G ™
Drawability (-)	OK	OK
Utilization of plasticity stock (-)	0,787	0,581
Thinning (%)	19,9	19,9
Wrinkling (-)	0,01	0,02

According to drawability analysis which was carried out in both programmes the stamping can be drawn without appearing of cracks at it. At analysis of utilization of plasticity stock (i. e. risk degree of stamping cracking), where numeric value represents the highest degree of deformation, no one software gives value 1. It means that the deformation lies under the limit deformations curve and the cracking does not appear at the stamping. The results evaluated by PAM-STAMP 2G ™ and AutoForm 4.06 programmes differs approximately about 26 %. The reason can be the different remeshing of stamping model and blank model during the calculation, influence of different mathematic model used by software but also influence of different software solver. At sheet-metal thinning analysis the same value of 19,9 % was evaluated by both programmes. The degree of sheet-metal wrinkling evaluated by AutoForm 4.06 software was lower than with the use of PAM-STAMP 2G ™ software.

5 STAMPING SPRING-BACK EVALUATION BY AUTOFORM 4.06 AND PAM-STAMP 2G TM PROGRAMMES

After drawing simulation and evaluation its results the critical place on the stamping, where the high degree of spring-back is expected, was determined (see Fig. 6). Before simulation of the spring-back the sections at the ideal shape of model of stamping must be defined in Catia software. In these sections the spring-back of the stamping will be observed, compared with final stamping ideal shape and measured by 3D testing instrument on the real stamping. The sections defined at the final stamping ideal shape, which corresponds to the part production drawing, are named as *"nominal"* and are in Fig. 6 marked by green colour.

5.1 Stamping spring-back evaluation by AutoForm 4.06 software

After defining of sections at the final stamping ideal shape the calculation of the spring-back can start in AutoForm 4.06 software. After finishing of spring-back calculation a new, spring-mounted geometry of the stamping is got. The result of the spring-back is on Fig. 7, where the *"nominal"* sections and spring-mounted geometry sections are compared right in the simulation software. The spring-back size can be measured here but because it is already evident from the picture that the spring-back gets rather large sizes (8 mm on one side, 9 mm on next side by estimation) and the geometry of the drawing tool must be corrected, it is suitable to import this new sections straight to Catia software, where the measuring of spring-back and correction of tool will be done.

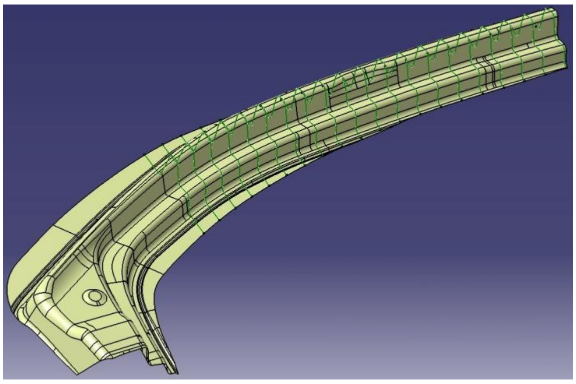

Fig. 6 *“Nominal”* sections defined at final stamping ideal shape in Catia V5R16 software

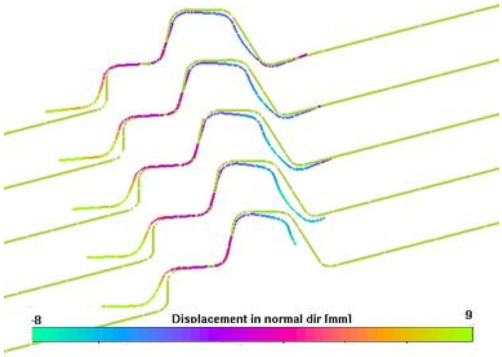

Fig. 7 *“Nominal”* sections in comparison with spring-mounted geometry sections of the stamping in AutoForm 4.06 software

The spring-mounted geometry of the stamping and the stamping geometry without spring-back are imported to the Catia software, where they can be compared in predefined sections. The sections of spring-mounted geometry are marked by red colour and they mean the spring-back of the stamping (see Fig. 8 and Fig. 9).

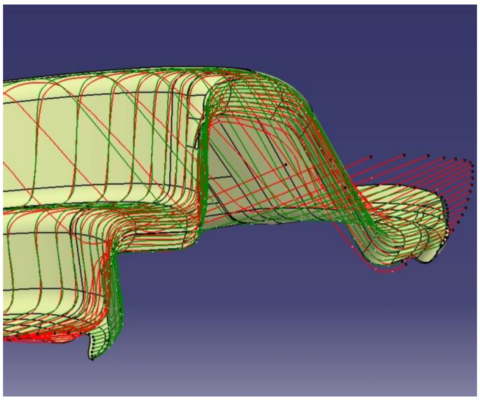

Fig. 8 The deviation between *“nominal”* sections and sections of spring-mounted geometry of the stamping from AutoForm 4.06 software

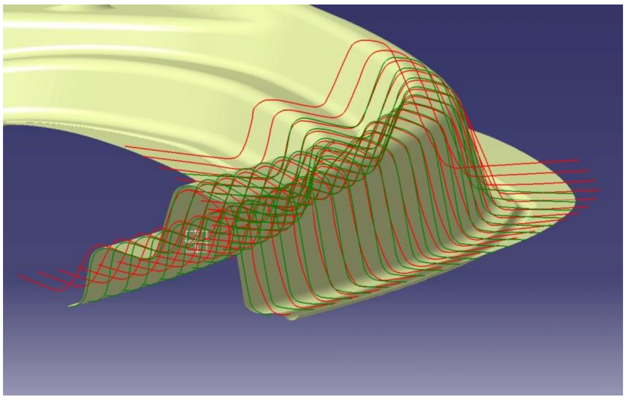

Fig. 9 The apparent spring-back of the stamping in the left part of the stamping from AutoForm 4.06 software

5.2 Stamping spring-back evaluation by PAM-STAMP 2G ™ software

The calculation of the spring-back was done in PAM-STAMP 2G ™ software too, *“nominal”* sections at the ideal shape of the stamping were leaved at the stamping. The resulting sections of the spring-mounted geometry were imported straight to Catia software for reason of the tool correction and they are marked by pink colour on the Fig. 10 and Fig. 11.

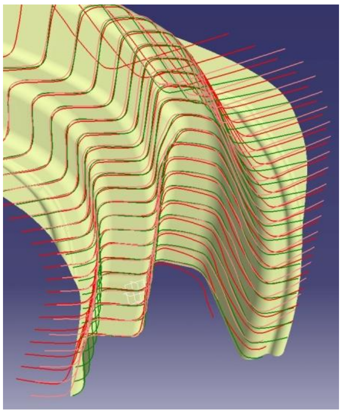

Fig. 10 The difference between *"nominal"* sections and and sections of spring-mounted geometry of the stamping from PAM-STAMP 2G ™ software

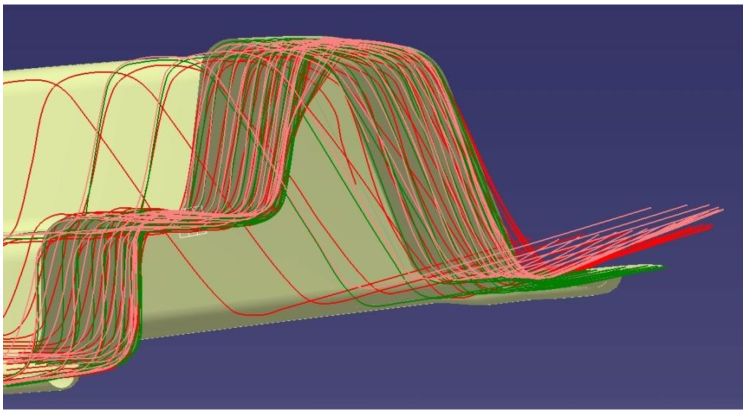

Fig. 11 The apparent spring-back of the stamping in the right part of the stamping from PAM-STAMP 2G ™ software

5.3 Comparison of the stamping spring-back calculated by AutoForm 4.06 and PAM-STAMP 2G ™ and measurement of spring-back deviations

Comparison of *"nominal"* section, spring-mounted section from AutoForm 4.06 software and spring-mounted section from PAM-STAMP 2G ™ software in cross section of the stamping is in Fig. 12. The spring-mounted section from PAM-STAMP 2G ™ software deviates from *"nominal"* section into the stamping and the section from AutoForm 4.06 deviates outwards in area 1 (see Fig. 12). In the area 2 in the end of the stamping the section of a new geometry from PAM-STAMP 2G ™ software gives a larger deviation from *"nominal"* section. Accurate deviations sizes in these critical places are in Fig. 13 and Fig. 14.

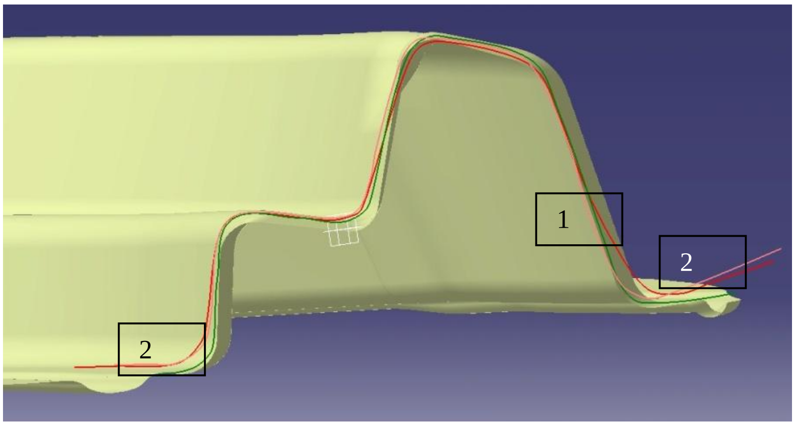

Fig. 12 Comparison of the spring-mounted geometries sections with *"nominal"* section

Comparison of the spring-mounted geometries sections with *"nominal"* section of the stamping with the measured deviations is on Fig. 13. At upper side of the stamping the deviations of the spring-back are the smallest, but they exceed the required tolerance of the spring-back, which is 0,5 mm. On the right wall of the stamping, there is the place (area 1 from Fig. 12), where the spring-mounted sections deviate from *"nominal"* section, everyone to the opposite side. The tolerance is exceeded again about 1 mm. The spring-back gets to the high values in area 2 – for spring-mounted section calculated by AutoForm 4.06 software it is 3,969 mm and for spring-mounted section calculated by PAM-STAMP 2G ™ software it is over 7 mm from *"nominal"* section. The similar situation is at the stamping opposite side.

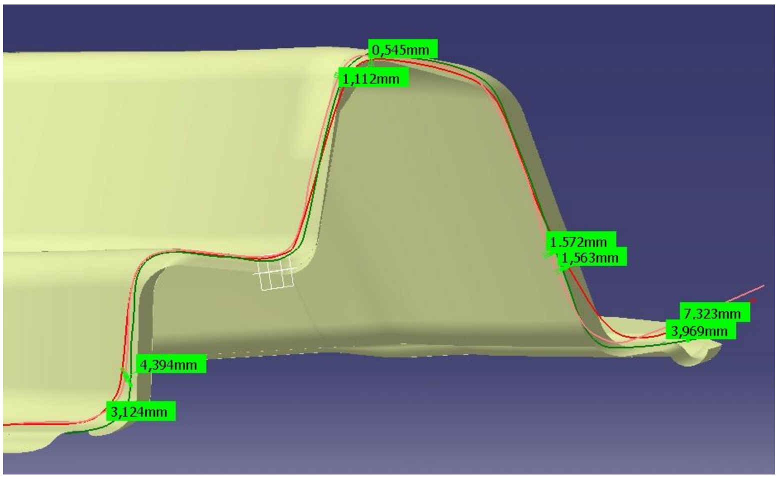

Fig. 13 Measured deviations of sections of the spring-mounted geometries from *"nominal"* section

The critical areas 1 and 2 at the stamping are shown more closely on Fig. 14. The deviations of spring-mounted sections from *"nominal"* section were measured and the deviations of two spring-mounted sections from each other were measured too. In critical area 1 is seen that *"nominal"* section passes between two spring-mounted sections, which are 1,98 mm far of each other. In direction lower under this place the spring-mounted section from the PAM-STAMP 2G ™ software deviates to nominal value, while the spring-mounted section from AutoForm 4.06 software deviates more from nominal value. In the area of transition radius this deviation is 4,875 mm, while the resulting value from PAM-STAMP 2G ™ software has half value here. The situation turns in a specific place, the section from AutoForm 4.06 software is closely to *"nominal"* section than the section from PAM-STAMP 2G ™ software. The both spring-mounted sections give too large deviation from *"nominal"* section here, the deviation of the section from AutoForm 4.06 software is 4,516 mm, the section from PAM-STAMP 2G ™ software is about 2,12 mm further.

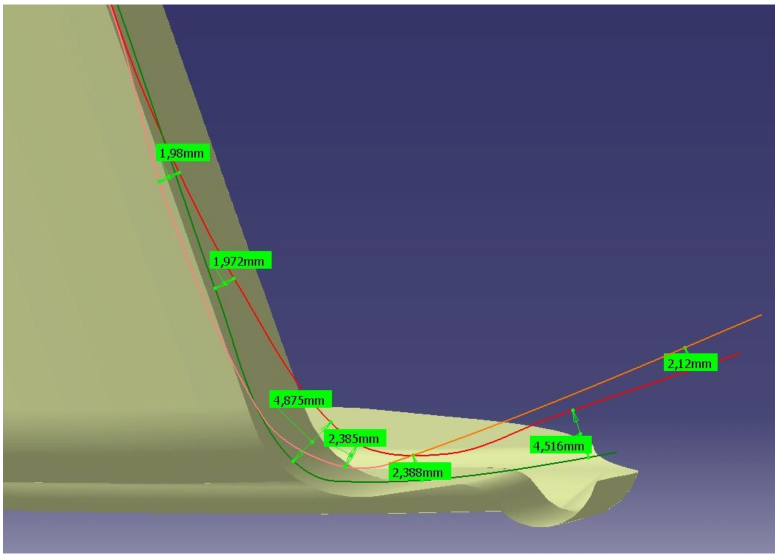

Fig. 14 Measurement of the deviations of both spring-mounted sections geometries from *"nominal"* section in critical areas 1 and 2

Because the deviations of the spring-back get to the high values and exceed the required tolerances of the stamping, correction of the drawing tool must be done to eliminate this spring-back (see 7).

6 DRAWING TOOL CORRECTION FOR ELIMINATION OF THE STAMPING SPRING-BACK

Calculation of the stamping spring-back in both softwares showed a great deviations of the stamping from its ideal shape, so it is necessary to make a correction of the tool model to eliminate this spring-back. This problem can be solved by decreasing or by incrementing of angle between the stamping and the drawing tool, eventually by remodelling the part of the stamping so that the given edge must get into the required tolerance specified at part production drawing after spring-back and the sections at stamping after drawing must be the same as the sections defined at the ideal shape of the stamping. It can be named as so-called transformation of tool surfaces to the opposite side from spring-mounted surface in the size, which was measured in Catia software. By this correction the spring-back beside required boundaries will be eliminated and the stamping will be drawn in tolerances specified at part production drawing.

After this correction the simulation of stamping spring-back must not be done because by correction of drawing tool surfaces leads to safe elimination of great stamping spring-back. Eventual next deviations are corrected right at the drawing tool by toolmaker, who is in charge of the tool and its function. On the basis of the choice of production technology, the analysis of drawing process simulation and after correction of tool model the drawing tool for drawing of this stampings is made. After functional tuning of drawing tool the first set of the stampings, which contains mostly 8 to 10 pieces, is drawn. These testing stampings are measured on the testing instrument, which is specially made for this shape of the stamping (see 8).

7 RPS POINTS AND 3D MEASUREMENT OF THE STAMPINGS SET REAL STATE AFTER DRAWING

The measurement is realized on 3D CNC measuring machine, which is used for 3D dimensional control of products in production. A shape deviations, location of holes, proportion of holes and deviations of contour are measured. Values of permitted deviations are specified at part production drawing. The stamping is placed to testing instrument on RPS surfaces and centred on RPS holes. RPS points and surfaces are helping referential points which serve for the same stamping setting-up against the measuring system. These points are chosen into technological base of stamping to achieve the same setting-up of all other stampings. System of RPS points limits the technological base from which another dimensions can be measured. It is going out always from more measured records and it is calculated with the average values of deviations when correcting the dimensions.

The the result of the measurement is the well-arranged form which shows measured places on the stamping and their dimensional values. These values are marked by coloured symbols and by numerical value, which shows the deviation from real dimension. The values, which are suitable for specified tolerance, are green, the yellow values are boundary ones. The unsuitable deviations are marked by red colour and they must be corrected by correction of drawing tool. Simulations before production of stampings identified the spring-back, but the deviations did not have large values. There were only a few places, where the deviations were behind a tolerance field and it was necessary to make a correction of the tool. The correction of tool is made by change of tool shape – at positive deviations by milling or grinding of the tool and at negative deviations by overlaying of weld bead by the help of specialized electrodes (hard-metal) and subsequent milling (grinding) of drawing tool.

The results of the measurement of really drawn set of tested stampings with the use of 3D coordinal machine after correction of tool are shown in Fig. 15. All deviations are in the green areas, it means that the stamping is ready for production.

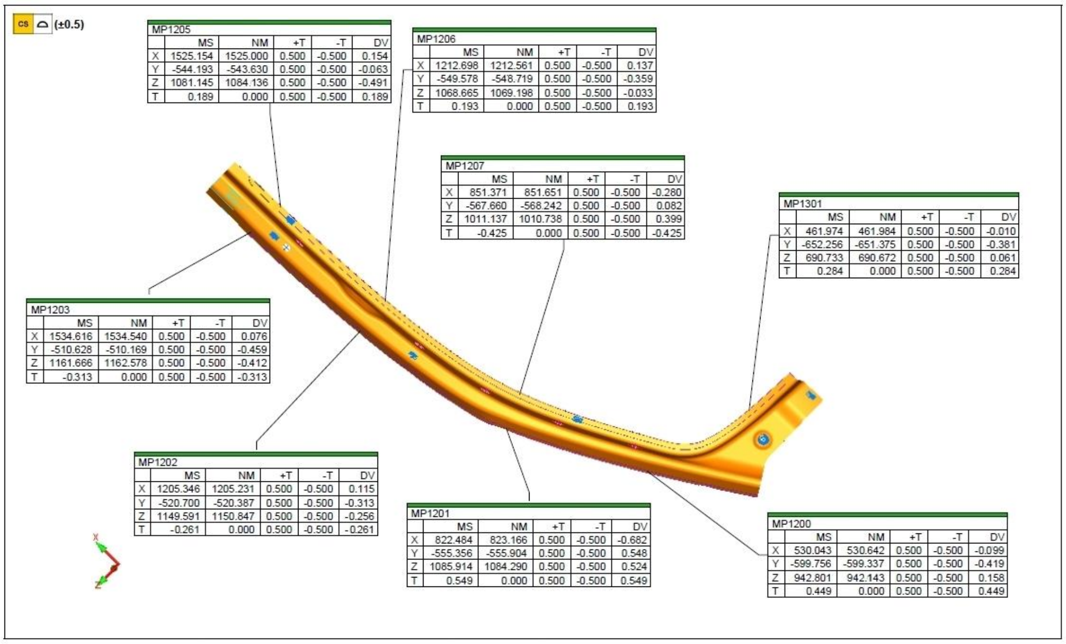

Fig. 15 Stamping shape deviations from specified tolerances at product drawing of really drawn first set of tested stampings measured by 3D machine

8 CONCLUSIONS

At spacious stampings with large shape transitions and with the deep draw a danger of large spring-back in the stamping after drawing process exists. These deformations can be such large that the stamping need not suit to tolerances specified at part production drawing after its drawing. For the stampings with menace of the spring-back, the endeavour to precede this state by correction of the drawing tool exists so that the stamping after drawing stayed in tolerance field required by customer.

For the smallest spring-back of the stamping and for optimal conditions of drawing the draw beads were designed, next the force on draw beads during the drawing and binder force. These all for required sheet-metal material HC450X (see 2). From four performed variants the optimal beads were chosen (see 4), which are the most suitable for drawing of this asymmetric stamping – inside reinforcement of the car front door.

The drawing process simulations were done in AutoForm 4.06 (see 4) and PAM-STAMP 2G ™ software (see 5) with the same boundary conditions so that the results had the same base of input dates and the calculations from the both software were comparable. From simulations the fact is resulting that the designated part is formable without the risk of the crack, with usable values of thinning of the sheet-metal and wrinkling.

For evaluation of the spring-back in testing places of stamping and for their comparison with basic *"nominal"* model after simulation of spring-back, the creation of the sections at the stamping was necessary. It was found, that the results in individual sections differs slightly of each other (see 6), which can be caused by different solver in each software. Both softwares determined with certain tolerance the places, where the stamping spring-back appears after drawing process. Thanks to these CAE calculations, the drawing tool can be corrected in an electronic form of a model so that the stamping made with it later is in tolerances specified at part production drawing (see 7), so by it is prevented from lengthy process of tuning of real drawing tool. After the first drawing of the testing set of the stampings, this testing set is measured on 3D measuring machine (see 8). If the exceeding of required tolerances is finding, problem is solved by immediate correction of drawing tool right in production.

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Results in the contribution were achieved at solving of specific research (project SP/201091 ”Technologic Design – Numerical and Physical Simulation“ solved in year 2010) at Faculty of Mechanical Engineering of VŠB – Technical University of Ostrava.