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SIMPLIFIED APPROACH METHOD OF CALCULATING DRAWBEAD FORCE

Ph.D. Thesis summary

by
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1. The research task

Small - medium sized enterprises play a significant role in both the Hungarian economy as well as internationally. In the sheet metal industry many of these companies manufacture their products using sheet metal stamping technology. Design software systems have an enormous importance in the production, die and manufacturing processes. Finite element software modules or programs provide the method for calculating the technical parameters in sheet metal forming processes. However, the finances are not always available to purchase these programs and there is not always a need for such complex analysis. In many cases requirements can be met through simplified calculations of the basic theory of elasticity variants.

An important quality factor in sheet metal stamping technology is the control of material flow. The control of force load is provided with the blank--holding force and where required with draw-bead strength through draw-beads. The amount of drawbead forces varies according to the geometry of the draw-bead, material features of the plate, friction coefficients and the draw-bead height.

The general design principles applying to draw-bead formation are useful for reference only.

The formation and installation of draw--beads, even in modern manufacturing, is often still carried out through trial and error: based on practical experience. When forming the die small draw-bead measurements are initially used - radii smaller than a semicircle draw-bead - to achieve large form changes avoiding the possible dangers of splitting. To eliminate this danger the groove or the draw-bead radius is increased. These changed are often carried out through welding or filing. At the same time the true bending radii is a factor of the height of the draw-bead and reacts sensitively to any changes to it. Calculating the draw-bead force is a vital part of die and technology planning. This study wishes to assist in the calculation of the draw-bead force through tested and improved processes. Numerous methods exist for the calculation of draw-bead force. This study deals with a computer program that is commonly accepted as easy-to-use in practice and accessible to all.

The main objective of this study is to examine the general validity of the method that was selected, and to propose relationships that reflect geometrical variables appearing during the sheet metal stamping process. Using these relationships the mathematical model will be able to be used for calculation of draw-bead forces at any draw-bead height to a degree of error acceptable in the technical practice.

The above objectives will be achieved through the following:

- The examination of the validity of the KLUGE process with model testing - strip test – on various materials with varying draw-bead geometry and draw-bead height.

- The adjustment of the method's core mathematical model, based on theoretical principles to proposed calculated relationships reflecting the true geometrical variables and the testing of the validity of these calculations.
- Using model testing, the comparison of the further developed simplified calculation method's values with the results in finite element simulations.
- The justification of the conclusions drawn from the examinations obtained from the measurements of bends on real sheet metal non-circular symmetrical work pieces of various materials.

2. The theoretical and experimental methods utilised

2.1 Review of literature

The force, which restrains material flow, acting through the draw-bead placed on the drawing edge of the die and the blank-holder draw-bead built into the blank-holder, is the total the forces necessary to overcome friction and the multiple bending and unbending of the metal sheet going through the draw-bead.

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There are a large number of models for calculating draw-bead force. All of them are built on the model proposed in the studies by *Swift 1948* and *Nine 1978*.

Swifts work dealt with the bending and unbending of strip pulled through a circular pin. The observations and conclusions were all based on the assumption that the plate bends and unbends at the place of contact or in its vicinity. Swift assumed that the curve of the plate and the form changes that occur in the metal and so the stresses that occurring in the material were constant. The linear hardening material model was used in the calculations. The total force required was given as the force required to overcome the bending and unbending and friction.

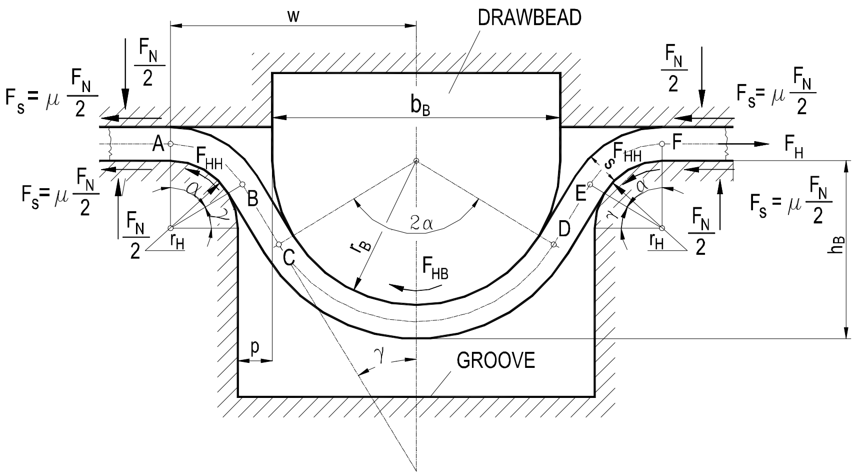
The experiment and simulation apparatus developed for measuring drawbead forces, which Nine published in his study, provided the opportunity to examine the draw-bead reaction mathematical model and also calculating the average friction coefficient present at the draw-bead reflecting friction relationships.

The calculation models for draw-bead forces primarily differ in which method they use and which factors are taken into account in calculating the force required for bending and unbending.

A part of the work was carried out with virtual work solving the problem. The other part used the balance moment equation prescribed for the centre of the curve and calculates the force required with a numerical equation solution or the familiar analytical solution. Regarding the material laws, the features of material behaviour, the hardening, the Bauschinger effect and the anisotropy were taken into account in different ways and amounts.

The first calculation of draw-bead forces with the finite element method was published in 1996. In the publication the model is based on the large stain elasto-plastic formation theory and further takes into account the friction coefficients. A 20% difference is noted between the simulated values and the Nine experimental findings.

In the professional literature the KLUGE type method together with its deficiencies is regarded as useful. The method takes into account the deformation of the sheet in a completely idealised way. The assumes a clean bend in calculating bending and unbending force occurring at various points. In the calculation of external moment the draw-bead force is ignored. An identical



angle of wrap *insert A* is recorded for draw-bead and the groove. The *insert A* angle of wrap is derived from the draw-bead geometry and the depth of the draw-bead. Friction is taken into account using the relationship valid for rope friction. The bending radii are in all cases the radii of the draw-bead and the groove.

The Kluge type model

The draw-bead force is calculated with this equation:

$$F_H = \left(\left\{ \left[\mu . F_N + \frac{k_{fA} s^2}{4(r_H + \frac{s}{2})} \right] e^{\mu \alpha} + \frac{k_{fB} s^2}{4(r_H + \frac{s}{2})} + \frac{k_{fC} s^2}{4(r_B + \frac{s}{2})} \right\} e^{\mu . 2\alpha} + \frac{k_{fD} s^2}{4(r_B + \frac{s}{2})} + \frac{k_{fE} s^2}{4(r_H + \frac{s}{2})} \right) e^{\mu . \alpha} + \frac{k_{fF} s^2}{4(r_H + \frac{s}{2})} + \mu F_N$$

The theoretical amounts calculated differed from the data obtained from strip test by an average of 20-30% including the results measured on small draw-bead heights.

To partially eliminate the differences between the theoretical findings and the experimental data, Kluge proposed a semi-empirical correlation based on the measured results. He calculated the constants of the equation for deep drawing steel.

2.2 Examination of the validity of the KLUGE-type method for the plate strip drawer

The strip test can be used for the modelling of the reactions occurring in the drawing and stopping draw-beads. During the test, sheet metal strips of varying sizes are pulled between two parallel bits, recording the required forces for the FN *insert plate stamping and the FH *insert drawing force. Stopping draw-beads of different geometry and adjustable height can be attached to the bits to simulate the technological conditions that occur in industrial practice.

To achieve the objectives of this study the tests were carried out on steel and aluminium of various quality metal sheets. This was done with different stopping draw-bead geometry and draw-bead height at given geometrical parameters at 8 different FN clamping forces with pressure at 8 different levels between 2.5 and 12.0 N/mm2.

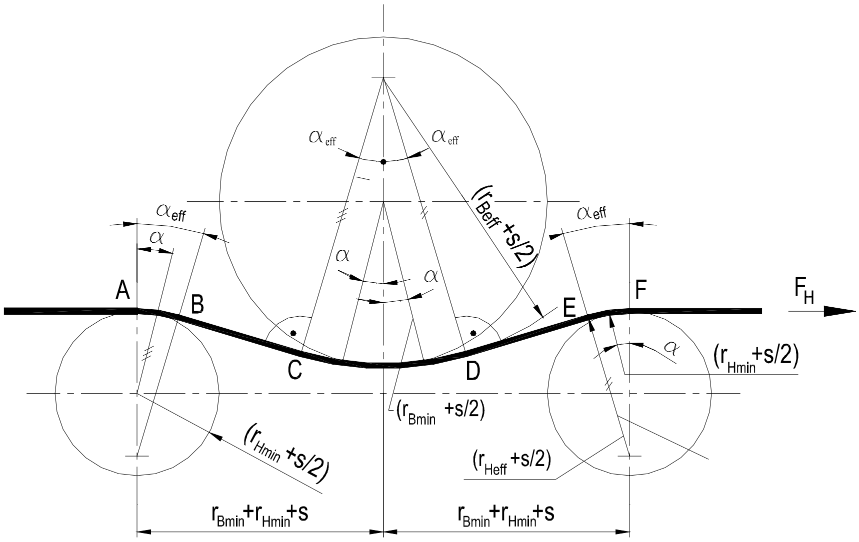
When comparing the data obtained from the measurements with the calculations with the Kluge-type method it can be concluded that the process is satisfactorily exact in the case of large draw-bead heights but in the case of small draw-bead heights it loses its validity. The real radius of the bend differs from the radii of the draw-bead. The real radii are much larger.

2.3 Calculation methods for real geometrical conditions of bending radii

The KLUGE-type idealised model assumes total symmetry on the leading and leaving sides of drawing draw-bead and as well as this that the sheet follows the radii of the draw-bead and of the groove so that the sheet passes straight along the common tangent of the draw-bead and the groove.

The features of the improved more exact KLUGE-type model are the following:

- symmetry on the leading and leaving sides;
- the plate does not follow the radii of either the draw-bead or the groove but have the larger values :(r_{Beff} +s/2) and (r_{Heff}+s/2);
- the plate is, in realty, placed between the draw-bead and groove at the above effective radii joint contacts;
- the theoretical AEFF angle of wrap that is created here is equal at the draw-bead and the groove.



The principle of the mathematical model used for the calculation of bend radii

Based on the model the bending radii reflecting real relationships are between the minimum α_{min} and maximum α_{max} angles of wrap α_{eff} and is calculated according the equations below:

$$r_{Beff} = \frac{\mathrm{tg}\,\alpha_{eff}\left(\left(r_B + \frac{s}{2}\right) - \frac{s}{2}\,\mathrm{tg}\frac{\alpha_{eff}}{2}\right) - h}{\mathrm{tg}\,\alpha_{eff}\;\mathrm{tg}\frac{\alpha_{eff}}{2}} \quad ,$$

$$r_{Heff} = \frac{\mathrm{tg}\,\alpha_{eff}\left(\left(r_H + \frac{s}{2}\right) - \frac{s}{2}\,\mathrm{tg}\frac{\alpha_{eff}}{2}\right) - \left(h_B - h\right)}{\mathrm{tg}\,\alpha_{eff}\;\mathrm{tg}\frac{\alpha_{eff}}{2}} \quad .$$

2.4 Assessment of the calculation

The examination of the validity of the proposed equations for calculating the bending radii reflecting real relationships took place with the comparison of the calculated values with measurements of bending radii under the various geometrical conditions made with a coordinate measuring apparatus.

Based on the comparisons of calculated results with the measured data the following can be concluded for both steel and the automobile body parts:

- The calculation the bending radii reflecting real geometric relationships show good positive correlation with actual measured radii on the draw-bead edge.

At a given draw-bead height the average difference between the calculated and the measured radii is approximately 8%.

- The difference between the calculated and measured values on the groove's leaving side is still acceptable (12% the average difference). The differences in the calculated and measured values on the leaving side show large differences.

2.5 The analysis of the finite element simulation for the plate strip drawer

For the finite element analysis of the model the "PAM-STAMP" was used for solving the plastic forming problems. The finite element model was prepared taking into account the symmetry tasks. The mesh was built on the PAM' 98 rectangular solid elements. The contacts of the plate and the fixed die surface was modelled by contact elements. The material model was elasto-plastic. The calculation model used the HILL first flow assumption to measure anisotropy. The determination of the friction coefficient was carried out through a simple plate strip drawer test (*insert HB=0) of the different materials and was assumed to be constant at various surface pressures. The simulation was run with *insert r_H=3mm and r_B= 5mm draw-bead geometry and *insert F_N= 4.0; 6.0 kN clamping force.

The calculation of the bending radii reflecting real geometric relationships in the simplified approach method were carried out with the EXCEL program, without taking into account the decreases in the thickness of the metal sheets. The mean deformation hardening at different points in the bend were calculated with the 'n' hardening exponent appropriate to the total deformation value and taking into account the anisotropy effect,

The following can be concluded from the comparison of the finite element analysis findings obtained from the simplified systems with the measured data:

- In the case of steel good correlation was shown, at all heights, between the draw-bead force calculated with bending radii reflecting real geometric relationships and the data obtained in the finite element simulation. The differences were between 2.2% and 7.2%;
- The draw-bead values calculated with the simplified approach method and with the numerically calculated finite element method differed from the measured values in both cases by less than 20%, and further the related to the draw-bead height showed an identical tendency;
- Taking into account the asymmetry in the leading and leaving side of the groove there was greater correlation between the calculated and the simulated data;
- In the case of split hardening aluminium alloy, when the calculation is done with the real bending radii on the leaving side, or this is taken into account with a corrective factor, the results obtained from the simplified approach method and the finite element method show good correlation.

2.6 The analysis of the simplified approach method in a deep-drawing test series on various quality plate materials

The objective of the deep-drawing test series was to examine if the improved calculation method for draw-bead reactions can be applied in technological planning processes and in the forming of dies and therefore in practice. In the formation of different pieces in the test series the main consideration was, not only the comparison of measured and calculated values, based on the measured values to obtain information about the effect of the draw-bead end on clamping force. The test series on different materials consisted of six trial test types.

The measurement of the required drawing force F_B was carried out on four different materials at identical die geometry, blank-holder pressure and lubrication conditions with different draw-bead heights. All plates were formed with the PY E 250 type hydraulic press with a 300x200 mm r = 30 mm corner-rounding drawing tool. The draw-beads had a r_H groove radius of 3 mm and the draw-bead radius was 6 mm. The distance between the upper and lower parts of the blank-holder could be adjusted with screws and springs, which also set the draw-bead height.

The setting of the operation range was done on an experimental basis. At the time of deep-drawing of the pieces the deformation velocity, and the amount of lubricant used on the surface agreed with the values used in the strip test.

On the experimental apparatus the pump and the pressure gauge valves did not provide constant pressure, however, there was no opportunity to install a pressure accumulator. The F_N blank-holder force gauge recorded the changes in pressure and the transducer pack measured values were recorded by the measuring system. Knowing the real F_N blank-holder force provided the opportunity to appropriately correct the calculated F_B required drawing force, and thereby the chance to compare the measured and calculated values and an analysis of the practical usefulness of the simplified approach calculation system.

The measured real bending radii on the draw-bead side and on the groove leaving side for different materials and forms (drawn from different plates) in all cases showed close agreement with the calculated values. The difference between the measured and the calculated radii on the die side we on average 10% and on the groove side 5%. On the leaving side at large draw-bead heights the calculated and the real radii closely agreed while at small draw-bead heights the difference was great.

The calculation of the F_B required drawing force of the deep drawn pieces was carried out according to the so-called analytical method, which was proposed by *Deoge* and *Strakerjahn*. The comparison of the calculated and the measured findings clearly show that when the stopping draw-bead force is calculated with bending radii reflecting real geometrical relationships the calculated and the measured findings show good agreement even in the case of small draw-bead heights.

3. New findings

- I have worked out a useful model and calculation process for the more exact calculation of draw-bead forces further developing the Kluge method.
- Using model testing and finite element calculations I have proven that the calculation method that I have proposed in the case of small relative draw-bead height describes the real geometric relationships.
- Using deep drawing testing parts I have proven that the proposed method can be utilised with both steel and split hardening aluminium alloy.
- The proposed model and calculation method is also reliably useful in practical situations.

4. The opportunities for the practical application of the findings

The calculation of draw-bead forces at various draw-bead heights within a degree of error acceptable for industrial practice but using base software that is accessible offers assistance in production and die design.

It is worth mentioning as a further application opportunity that the improved model could be prepared within a doctorate thesis at the Budapest Technical University and can be utilised as a module of the sheet metal working technology design program developed in the joint Budapest Technical University and Széchenyi István University research tender TO23877 OTK .

I trust that this study has contributed to the existing results in this area, making the calculation of draw-bead forces, easier for working professions as well.

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