

Knowledge-Based System For Computer-Aided Process Planning With Finite Element Predictions

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Abstract

The knowledge-based system COFEX (Cold Forging Expert) has been developed to assist in the planning of the cold forging of a wide variety of tubular steel components. Following user-input of the required shape and dimensions of the finished forging, together with as many different sequences as desired, each operation is examined by the system by consulting the knowledge-base process rules and data. Messages give the reason if any of the operations is unacceptable. If manufacture by cold forging is feasible, the dimensioned drawings of the finished and semi-finished forgings, together with the process parameters are displayed. Subsequently the suitability of existing presses are checked or new ones specified, the cost of the forging is computed and the sensitivity of the costs to various factors assessed.

If heading is included in the sequence it can be checked by the finite element analysis whether or not plastic buckling and subsequent folding defect is likely to occur, and forging loads, stresses and strains predicted.

Keywords

Cold forging of steel, process planning, knowledge-based system, finite element analysis.

1 Introduction

Despite its advantages in material saving, excellent surface finish and tolerances, the industrial application of cold forging of steel is more limited than would be expected. The reasons can be found in many strict rules that need to be applied in the design of components for cold forging and in the often lengthy process planning, followed by the design and

specification of production equipment, economic analysis and concluded by the frequently expensive development work. Such range of specialized knowledge is not usually available to any individual. Furthermore, stresses and loads can not always be determined from simple theory or from the data sheets of the International Cold Forging Group and the prediction of forging defects would be difficult without more complex theoretical analysis. There are the reasons why the interactive computer program COFEX has been developed, which can be consulted quickly and effectively as to the suitability of different component designs and cold forging sequences and to obtain costs, to assist the process planner in finding the best solution for particular conditions. The program is for personal computers, implemented in a modular form, with graphics facility to provide fully dimensioned detail drawings of the finished and semi-finished forgings at every stage of operation sequence. The main part of the system is in PROLOG, interfaced in C with a finite element module in FORTRAN.

The architecture of the system is outlined elsewhere [2]. The program is built up from several modules: (i) to design the finish forging; (ii) to set the sequence of operations; (iii) to check the feasibility of every proposed sequence; (iv) to compute plastic deformation by finite element analysis; (v) to select production machines and, finally, (vi) to analyze the economics of the proposed forging design and sequence of operations. In what follows, the application of the system will be described on the example shown in Figure 1 [2].

2 Designing the forging

The shape and dimensioned of the finished forging are entered by selecting cylindrical and conical primitives and combining them along a common axis. The modular design of the system allows the addition of further primitives, if desired.

First the number of elements which are required to build the shape need to be given, four in the present case. Subsequently the user is asked to specify the shape and dimensions of the first building block, the solid cylinder, at the bottom of the display Fig 1. Then the shape and dimensions of the volume element next to the base need to be given, hollow cylinder of 25mm bore and 35mm outside diameters and 22.5mm height. Subsequently the third and fourth elements are specified. In this manner, required shape of the forging is built up from four elements, brick by brick, by interaction between the system and user. In the next step the system asks the user to input the material quality, in this case 040A12 steel. The program will use, in the computations, the stress/strain curve of the specified material and its fully annealed hardness available in the knowledge-base.

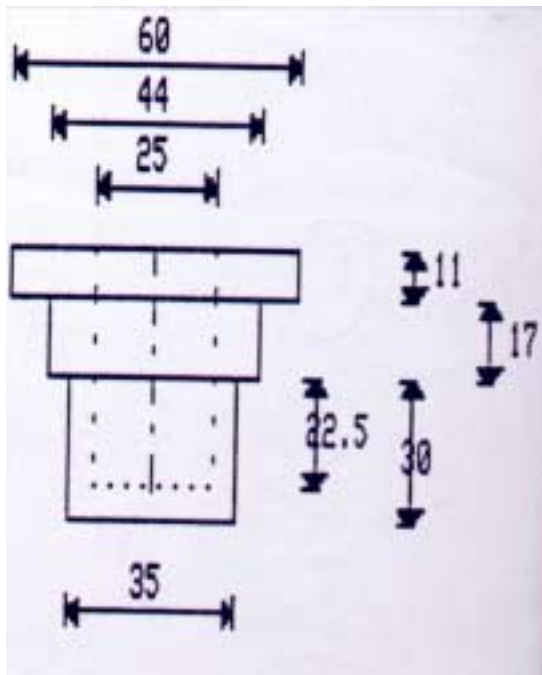


Figure 1. Flanged tube.

3 Sequence of operations

After the data relating to the shape and material of the forging, the geometry module is discarded from memory and sequencing module is loaded. By using this module, any number of different sequences can be designed and examined by the process planner, by selecting various operations in the desired order from the menu shown in Figure 2. The sequence may include can and tube extrusion, drawing/ironing, piercing, heading, or upsetting of a flange at the end or along a tube, in open or closed dies. The rule and data

relevant to these operations are available in the knowledge-base. The modular design allows the extrusion of this range of operations with relevant ease, by adding further rules and data to this module without disturbing the rest of the system.

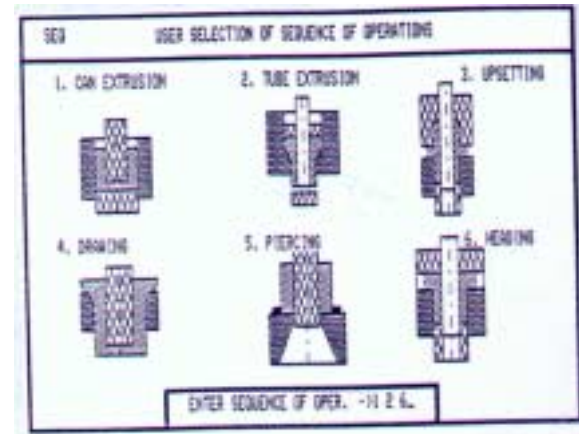


Figure 2. Menu for the selection of operations.

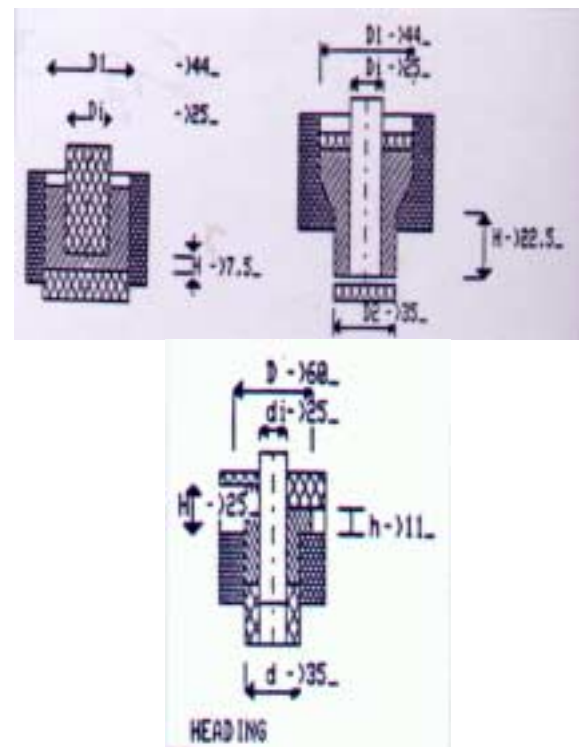


Figure 3. Sequence of operations.

In the present example three operations are selected, 1, 2, and 6: can extrusion followed by tube extrusion and heading. To compute sequence design, the nominal dimensions of the intermediate forging shapes following each operation need to be given by the user, as shown in Figure 3.

After saving the data relating to the sequence of operations, this module is discarded from memory and the next module is loaded which checks the feasibility of the sequence of operations, proposed by the user, against rules and data in the knowledge-base. First the user is asked to specify the desired tool life. The system then determines the stress in the most critical component, the punch, and compares it with permissible stress level available in the data base and appropriate for the specified tool life and displays the results, one by one for each operation. In the present case the permissible tool stress in backward extrusion is excessive, so the user is advised to reject the operation, but he is given two choices. Either the system's advice can be accepted: then the analysis stops. If the user-rules the advice of the system, the analysis continues and the various parameters are displayed, Figure 4. The system then checks the next operation, forward extrusion, found acceptable in the present case, so the results are displayed.



Figure 4. Display of data.

4 Finite element analysis

To check the third operation, heading, the module which obtained Figure 4 can be used once more, with

results of similar nature. Alternatively, the finite element module can be consulted, to find loads and stresses and obtain predictions relating to the plastic buckling and the forming of a folding defect, of the type described in [3]. Before the finite element module is loaded, the sequencing module is discarded from memory. Answering a query set by the system, the user must first select whether open or closed die heading need to be considered and must give the values of the various parameters such as the dimensions of the forging relevant to the analysis: the inside and outside diameters and supported height of the portion to be deformed, the boundary conditions and the required amount of deformation. In the present case the initial unsupported height of the tube subjected to the heading operation is 25mm, to obtain the required flange dimensions of 60mm diameter and 11mm thickness, the operation is open die-heading with a constant friction factor of $m=0.2$, at the tool/deforming material interface. In the next display information relating to the workpiece material must be entered: either the stress/strain curve of the materials from the knowledge-base can be used, or the constitutive equation for the other materials can be specified. In this case British Standard 040A12 steel with a stress/strain curve of $Y=320(1+85\epsilon)^{0.0185}$ was used in the analysis, where Y is the flow stress of the material and ϵ is the true strain.

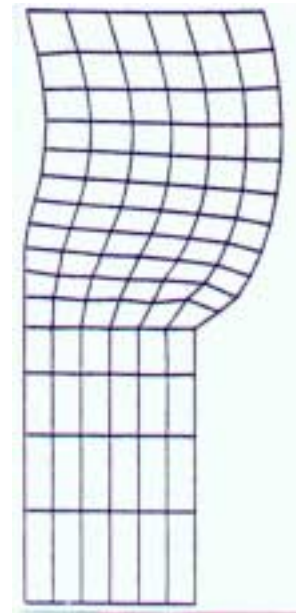


Figure 5 Deformed mesh in open-die heading.

The system then generates a finite element mesh of a predetermined form, using linear isoparametric elements and calculates the loads, stresses and strains which are placed in a data file for analysis. Subsequently the memory is cleared, a new file is

loaded into memory and the deformed mesh is displayed, Figure 5, which shows that open-die heading illustrated in Figure 3 is unacceptable in the present case, because plastic buckling would occur resulting in defective flange with a fold, so alternative forging designs and/or sequence of operations must be examined.

One possibility is to change the dimensions of the forging if service requirements allow, or use a subsequent machining operation to obtain the desired component geometry. Finite element analysis shows that buckling can be eliminated both by reducing the initial unsupported length of the tube, or by increasing its wall thickness/diameter ratio.

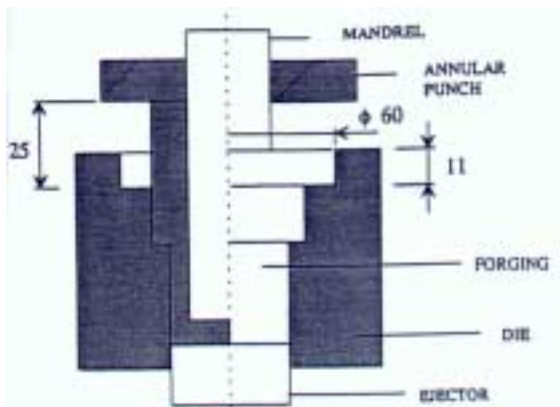


Figure 6. Closed-die heading

Changes to the component geometry are often unacceptable and secondary machining would be considered undesirable because of increased costs. Practical experience is confirmed by finite element analysis, that significant change in the deformation pattern can be obtained by upsetting flange into a closed die (Fig 6.) rather than using an open die. This method could be produced: (I) while in open-die heading the outer diameter of the flange follows "natural flow", in the closed-die heading the flange diameter becomes better defined and more accurate; (ii) the plastic bulge can be eliminated in some case with further deformation, because the deforming material is forced back to the mandrel once the outer diameter of the cavity is reached, producing a defect-free flange; (iii) several subsequent closed-die operations may be employed, so defect free, very large diameter flanges can be produced. While these advantages of closed-die heading are generally appreciated by experts, it is essential to carry out finite element analysis if the effects are to be predicted with any accuracy for particular conditions: the major

influencing factors are the dimensions of the flange and die cavity, and the number of heading operations.

Finite element predictions of the forging following closed-die heading is shown in Figure 7, clearly indicating that a defect-free flange could be expected: the improvement compared with Figure 5 is significant.

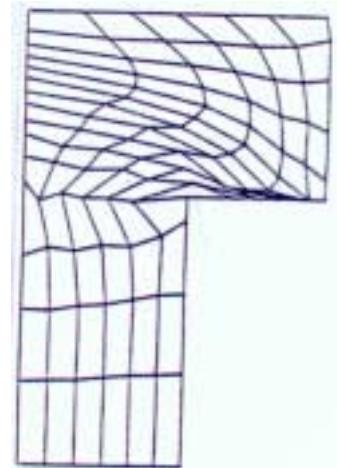


Figure 7. Deformed mesh in closed-die heading.

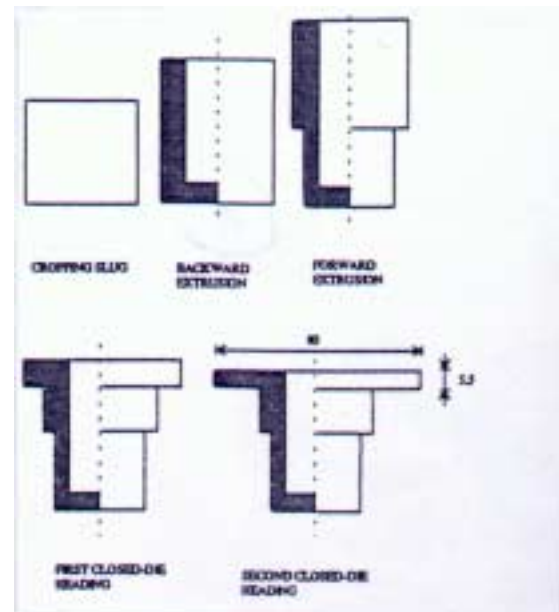


Figure 8. Forging with a larger diameter, thin flange.

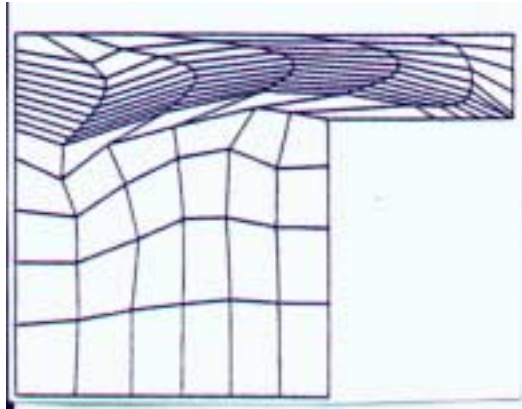


Figure 9. Deformed mesh in second closed-die heading.

If an even larger diameter would be required, such as that illustrated in Figure 8, a second closed-die heading could be applied to the flange-portion which was forged in operation 3. The finite element result is clearly favorable: the forming of a defect-free flange is predicted, Figure 9.

5 Dimensioning

The drawings displayed by the system for the various operations (Figure 3) so far show only nominal dimensions. The next module derives the actual dimensions of the slug and the forging after each stage of the sequence, which are essential for the tool design. In the computations of the following factors are taken into account by the system, subject to information supplied by the process planner: (i) the thickness of the lubricant film if inter-stage heat treatment is contemplated; (ii) the tolerances envisaged by the user; (iii) the clearance required on inserting the semi-finished forging into the die at each forging station; (iv) the elastic recovery of the forging when ejected from the die.

6 Press selection and cost study

Mechanical presses are selected for each operation by the last module of the system and the results are displayed, Figure 10. Alternatively, suitability of existing presses can be evaluated.

Finally the cost of the forging is computed by using discounted cash flow. To obtain results relevant to a particular organization and actual conditions, the user is invited to input the relevant cost factors: initial cost, unit cost of wages and materials, overhead, project life, annual production, etc. The sensitivity of costs to change in the various cost factors can also be examined and results displayed either in a table, or graphically, as required.



Figure 10. Selection of presses.

7 Conclusion

Some features of the interactive planning system COFEX has been demonstrated on an example. The program is in modular form, partly to allow the computations to be carried by using the restricted memory of a personal computer, partly to ensure that future changes and additions to the program can be made relatively easily, without affecting the rest of the system.

References

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