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An Integrated CAD/CAE System for Cold Forging Process Design

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Some progress on a research project aimed at designing and developing a computer assisted environment for the design of preforming sequences for cold forging are presented and discussed.
The main focus is on the "Generate, Test and Rectify" mechanism which controls the sequence design process, as well as on the classification and structure of the rules in the knowledge-based system. Details are given on logic and capabilities of the two modules devoted, respectively, to generate and analyse for suitability the forming sequences for multi-stage cold forging of solid and hollow rotationally symmetric parts.
Some application examples end the paper.

1. INTRODUCTION

A remarkable research effort has been recently made to develop process modelling of metal forming, mainly in the area of computer aided techniques. However, in spite of the significant progress in understanding the mechanism of deformation, knowledge of plastic phenomena often is not formalized for practical applications and still presents considerable gaps.

Inadequate knowledge, as well as the inherent complexity in modelling and planning forming operations, make process planning for a forged part a domain where knowledge is "expert-like" and comes from experience gained through long practice. Consequently, process planning activities which could take direct advantage from process simulation (such as assessing the feasibility of a forming operation and parametrizing it) are still largely experience based.

The above reasons have substantially retarded the development of process planning systems for forging. Not only CAPP systems for this technology are extremely restricted in number, but the considerable effort to develop CAPP systems in machining and, more recently, to upgrade them to a working industrial tool has not been matched in forming.

Today, the existing prospective tools based on GT classifications of forged parts have not yet formalized for process planning purposes, and the computer driven process planning systems [1-11] -including those based on A.I. techniques- are, at the most, at the experimental prototype stage.

The paper presents some progress on a research activity aimed at designing and developing a computer-assisted environment for the design of preforming sequences which is part of a comprehensive and integrated CAD/CAE system for cold forging technology in the automotive industry (Fig.1). The main focus is on the generative rule-based approach in designing the operation sequence.

The first part of the paper outlines and justifies the Generate, Test and Rectify (G,T&R) mechanism on which the sequence design process is based. The latter part of the paper illustrates present capabilities of the two modules devoted, respectively, to the sequence generation and test.

2. THE "G,T&R" APPROACH IN DESIGNING THE SEQUENCE

The design of a suitable sequence is one of the most critical responsibility in planning a multi-stage cold forging process. It directly influences all the other decisions required before the work-planning is completed.

According to the criterion of acceptance, an operation sequence can be *feasible, realizable* or *suitable*.
Feasibility of a preforming sequence is an intrinsic feature. It implies that blanks are formed

at the different stations without surface or inner defects. Additionally, the sequence does not include unnecessary extra preforming steps.
Realizability pertains to the actual execution of the process by given resources. A realizable forging sequence has to be instantiated for defined presses and handling devices.
Suitability refers to the "goodness" of the sequence design. It matches the technical success and a good economic balance, the latter being dependent, for instance, on tooling and operating costs.

non-deductive current-practice based approach for the domain of planning and designing and, specifically, for the problem of designing *suitable forging* sequences.
As in other guessing methods, the basic idea of the G,T&R strategy is fairly simple: "*Generate* an initial solution (hypothesis) and *Test* it. If the test produces failure, try first to *Rectify* the solution, and *Regenerate* it only if rectification is not possible". An automatic sequence design based on the G,T&R approach requires that the *test* as well as the *rectify* subsystem be automatic too.

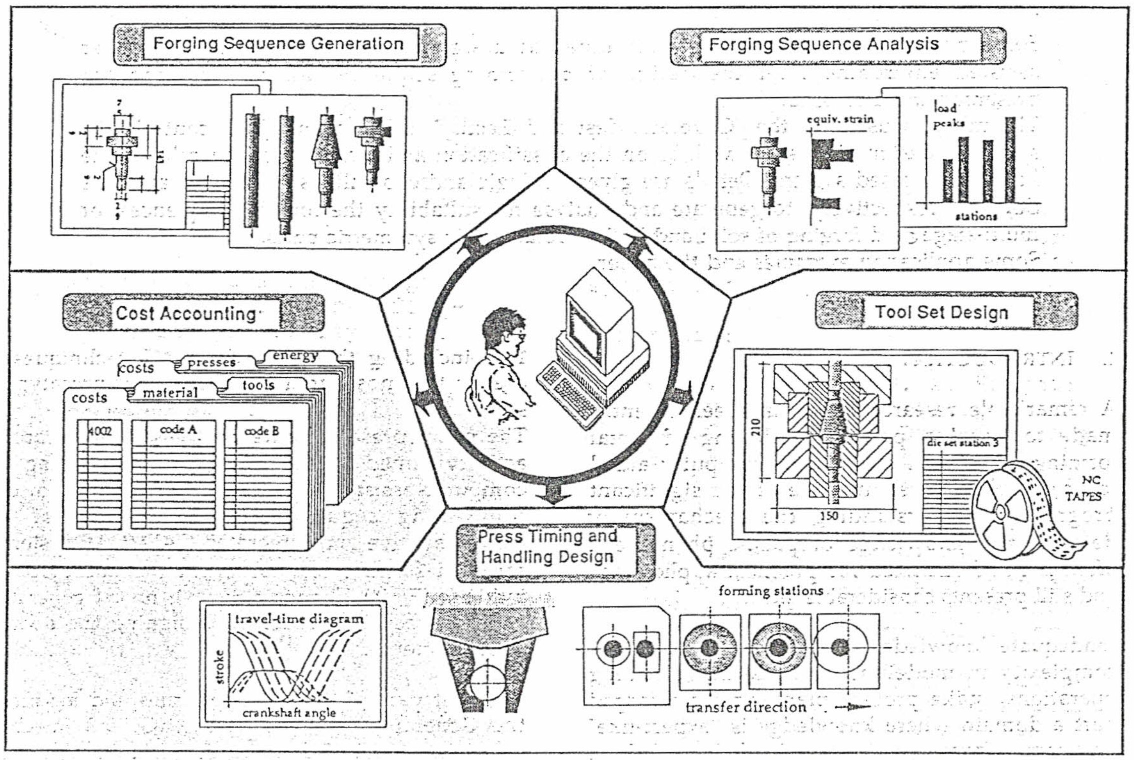

Fig. 1 Modules in the CAD/CAE system for the design of the cold forging process.

The level of acceptance of a sequence reflects nature and extension of the knowledge involved in the design process and determines the design approach as well. While the practicability of a *deductive* approach in designing a *feasible* forging sequence is well established [1,2, 5, 8 and 10], no deductive system is known which is capable of generating suitable sequences. The practice of using a sequence as a basis for improvement when a new suitable forging sequence is required reveals a knowledge of the forging technology that is inadequate to deduce a suitable sequence.

The G,T&R strategy, as other recoursive strategies such as H&T (Hypothesize and Test), provides a

When applied to the specific domain of the forging sequence design, the hypotheses are the generated feasible sequences; the tests assess realizability and suitability of the hypotheses while the rectification procedure, when invoked, modifies unsatisfactory features of the generated sequence revealed by the testing. Rectification measures are concerned with ordering and grouping forging operations in a different way, modifying operation capabilities, etc. Any rectified sequence maintain the main features of the unrealizable or unsuitable sequence, such as material and geometry of the forged part, billet diameter and, to some extent, mechanical characteristics of the finished part. On the other hand, number of forging stages and load peaks at the different stations usually change. Regeneration implies a more substantial change of the sequence, involving modification of geometry and mechanical characteristics of the forged component.

One important result of the G,T&R approach is that it is possible to keep separate the knowledge domains pertaining to generation, testing and rectification. This separation reflects nature and organization of current knowledge of cold forging and, additionally, permits the three functionalities to be developed independently.

At the time of writing, an experimental system consisting of the generation and test components of the G,T&R system have been developed and related procedures formalized in a rule-based representation. The system is capable of generating feasible sequences for solid and hollow rotational parts, as well as testing sequences for suitability on the basis of load-peak and energy-consumption distribution at the different stages and effective strain accumulated in the forged product.

A short description of the approach to generate feasible sequences and test them automatically is given in the following. Some application examples illustrate the capabilities of the system at the present stage of development.

3. GENERATION AND TEST OF SEQUENCES

3.1 The generation procedure

The basic structure of the procedure for the generation of feasible sequences which are hypotheses in the GT&R mechanism is shown in the diagram of Fig.2. Each subtask involves a number of decisions to be made before the next subtask is undertaken. Since the decision logic is formalized in terms of rules, the diagram indicates the criterion in grouping the rules, as well as the order in which the groups of rules are consulted.

The activities pertaining to the first subtask are the input of the material and geometry of the forged component, checking it for formability, and then classifying and coding of the shape features of the part.
The geometric data come from the CAD system, where the part profile is automatically extracted and the relevant features recognized.
The system for part classification and coding has been designed in order to access the files containing the sequencing rules corresponding to the particular class of the part, which include rules for selecting the billet diameter range suited to that family of parts, as well as the order and combination of the different cold forging operations. The classification system groups the components into families according to dimensional and shape attributes and, at this stage of development, covers most of the rotationally-symmetric cold forged components, solid as well as hollow.

At the second subtask, the geometry is split into basic elements (simple cones, cylinders or curves; solid and hollow), this permitting a representation of the part geometry suitable for the next subtask. Afterwards, the component is oriented and the cutoff length is calculated.

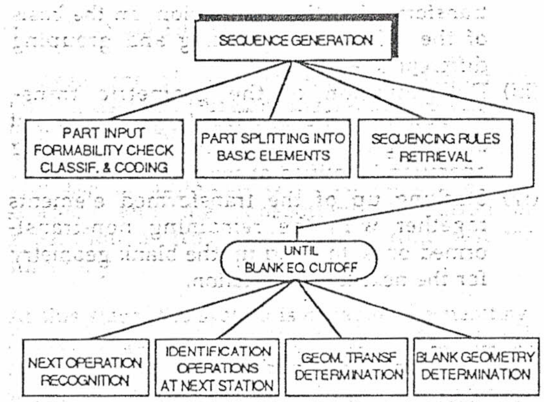

Fig.2 Structure of the generation procedure

When the third subtask is undertaken, the file of the sequencing rules suitable for the specific part family is accessed. The appropriate range of the wire/billet diameter is provided, together with a list including all the possible principal operations related to that class of part, ordered according to sequencing rules. Such a list merely indicates the precedences that each of the principal operations takes over the remaining ones. The grouping rules are applied separately; the individual operations -already ordered according to the precedence constraints- are assigned to the different stations on the basis of the class of the part and the number of stations available on the machine.
Both the sequencing rules –represented by the list of principal operations– and the grouping rules can be edited by the user, any change being temporary and, therefore, affecting only the current generation process. Alternative rules can be stored for the same part family.

The fourth subtask is the most decision–intensive procedure and this generates the geometry of the corresponding intermediate steps. The direction of the generative process is the reverse of the forming sequence with the initial and final states in the generation path being, respectively, the final cold forged component and the billet or wire cutoff.

As shown in the diagram of Fig. 2, the system works by modifying the basic shape elements until they take on the geometry of the corresponding portion in the wire cutoff. The decision logic directing this transformation has been divided into the following steps:

(i) Recognition of the forming operation to be performed as the next operation on each of the elements;

(ii) Identification of the basic elements to be transformed at the next station, on the basis of the rules for sequencing and grouping different operations;

(iii) Determination of the geometric transformation to be applied to each element according to the capabilities of the forging operation identified at the previous step;

(iv) Stacking up of the transformed elements together with the remaining non-transformed ones, to build up the blank geometry for the next forming station.

3.2 The Testing Procedure

This section outlines the automatic procedure developed for testing for suitability the forming sequences. At the current stage of development, the procedure is capable of evaluating the load peaks and the energy consumption at the machine stations as well as the effective strain distribution accumulated in the workpiece.

Independently of its use as a module for testing feasible sequences integrated into the G,T&R system or as a stand-alone analysis procedure, the current testing procedure consists of the following steps (diagram of Fig. 3):

In step (i), the program accesses the data files describing the geometry of the blanks corresponding to each stage of the proposed sequence. The blanks are then automatically classified and coded on the basis of the inner basic-shape to distinguish solid blanks, blanks with cavity (single or double, stepped and non-stepped) and with a through bore.

In step (ii), the program analyses automatically the pairs of blanks corresponding to adjacent stations. For each pair, the blank geometry is split into elementary volumetric elements and the correspondence between these elements in successive forming stages is then established.

Step (iii) of the program is devoted to the automatic recognition of the forming operations performed at each station of the machine together with the related deformation data. To this end the deformation involved in the corresponding volumetric elements is processed by a "pattern recognition" logic based upon more than twenty decision tables.

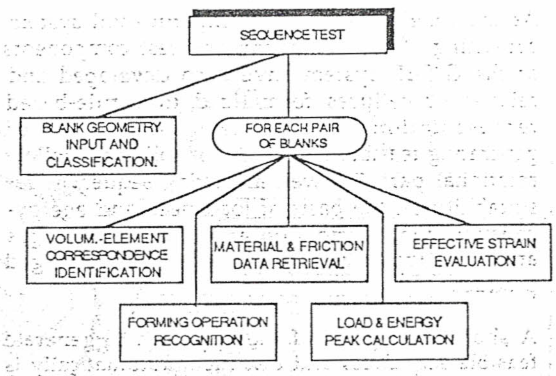

Fig.3 Structure of the sequence test procedure

At step (iv), the program accesses data files to calculate the material current flow-stress and the frictional resistance at the material-tool interface. The load peaks as well as the energy-consumption distribution at the different forming stations are then calculated on the basis of the recognized operations, the relevant deformation data, the material flow stress and friction coefficient.

Lastly -step (v)-, the effective-strain distributions accumulated in the the blanks at the different stations are evaluated. In calculating the strain, only homogeneous deformation is taken into account in determining the total effective–strain, the contribution of the redundant deformation being neglected.

4. APPLICATION EXAMPLES

In order to illustrate the capabilities of the system at the present stage of development, examples are given of the output obtained from generating and testing some forging sequences for two workparts. Figures 4*a* and *b* show two sequences for the same solid part; two different colours are used to distinguish adjacent basic elements.

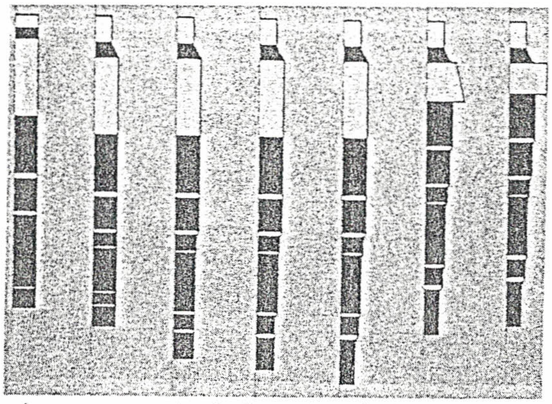

Fig. 4a Feasible sequence for a solid part.

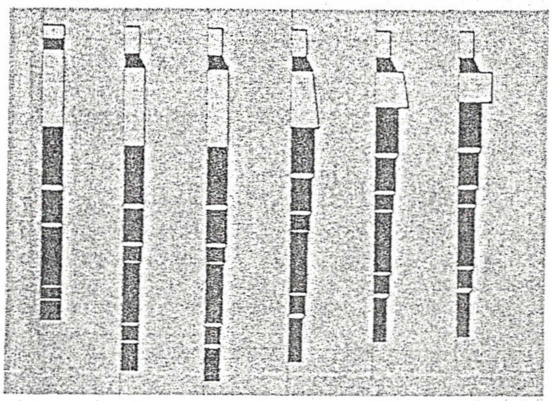

Fig. 4b The sequence of Fig. 4a after rectification.

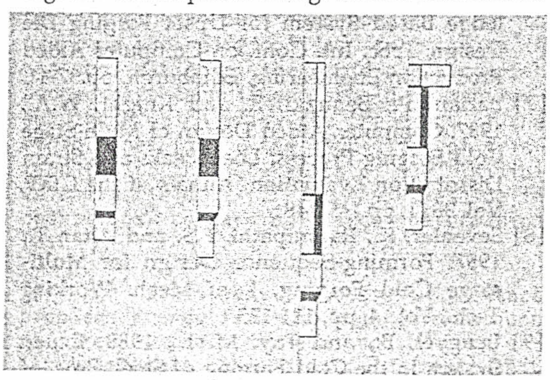

Fig. 5 Four-stage sequence for a hollow part.

The first sequence is a feasible sequence which results from the generation stage. It consists of seven stages; reducing, extrusion and upsetting operations are performed at different stages and the deformation by upsetting is allotted to two stages. The latter sequence (Fig.*4b*) results from a rectification The rectification measures are:

- combination of reduction and extrusion at the second stage,
- combination of forward extrusion with the first upsetting operation at the fourth stage, and
- allotting the deformation by upsetting to three stages, as a consequence of a lower upset ratio.

Figure 5 shows the four-stage sequence generated as initial hypothesis for a SAE1015 steel bevel gear.
The distribution of the peak loads at the shearing and forming stations are shown in Figs. 6 and 7 for the sequences of Fig. *4a* and *b*, respectively. Figures 8 and 9 illustrate for a *regenerated* sequence of the bevel gear of Fig. 5 the energy peak distribution and the effective strain accumulated at the fourth stage.

5. CONCLUSIONS

A prototype of computer-assisted environment for the design of preforming sequences for cold forging has been developed.

The design approach is based on the G,T&R strategy and the consequent separation of generation of feasible sequences from test for suitability.

At this stage, the system is capable of generating feasible sequences for cold forging of solid and hollow rotationally symmetric parts and then test sequences for suitability on the basis of load-peak distribution in the different forming stages, as well as the effective strain accumulated in the blanks and the finished part.

Further developments are taking place both to extend the scope and operations currently covered by the generate and test components of the system and to design and develop the automated mechanism for the rectification and regeneration of the sequences.

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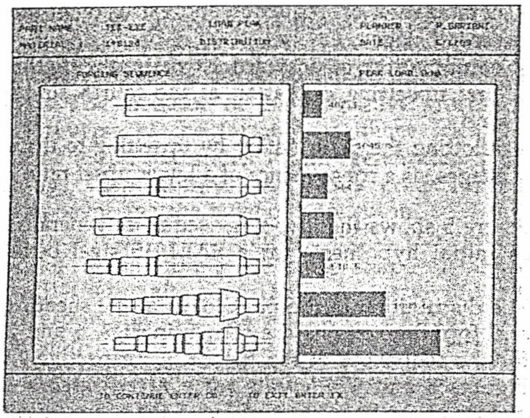

Fig. 6 Peak loads for the sequence of Fig. 4a

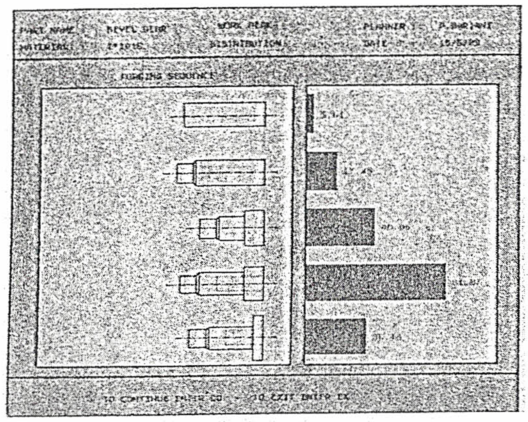

Fig. 8 Energy peak distribution.

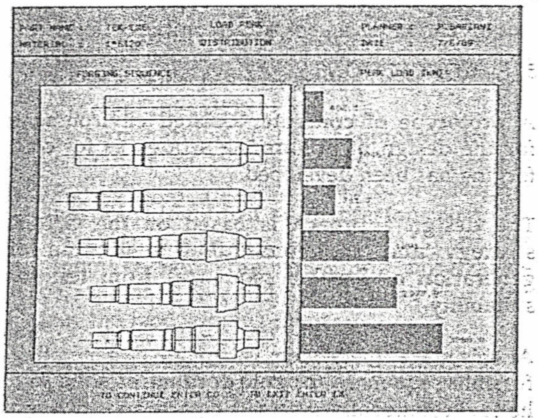

Fig. 7 Peak loads for the sequence of Fig. 5b.

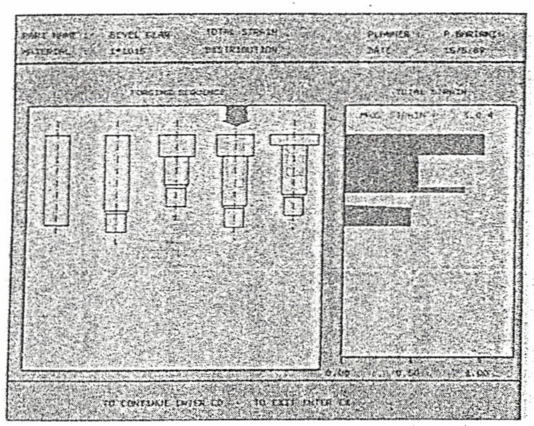

Fig. 9 Effective strain distribution.

REFERENCES

[1] Rebholz, M., 1981, Interactive Programming System for Developing Layout for Cold Bulk Forming, report No. 60, Metal Forming Institute, University of Stuttgart (in German).

[2] Davison, T.P. and Knight, W.A., 1984, Computer Aided Process Design for Cold Forging Operations, Advanced Technology of Plasticity, Proc. 1st Int. Conf. on Technology of Plasticity, Tokyo, Vol.1, pp.551-556.

[3] Bariani, P. and Knight, W.A., 1985, Computer Aided Cold Forging Process Design: Determination of Machine Setting Conditions, Annals of the CIRP, Vol. 34/1, pp. 245-248.

[4] Rebholz, M., 1985, Computer Aided Checking of Sequences in Forging, Proc.of 7th Int. Conf. on Cold Forging, Birmingham, pp.117-125.

[5] Badawy, A.A., Kulmann, D.J., Raghupathi, P.S. and Altan T., 1985, Computer-Aided Design of Multistage Forging Operations, J. of Mech. Working Tech., Vol. 11, pp.259-274

[6] Eames, A.J., Dean, T.A., Hartley, P. and Sturgess C.E.N., 1987, An Intelligent Knowledge Based System for Upset Forging Die Design, Proc. Int. Conf. on Computer Aided Production Engineering, Edinburgh, pp.37-41.

[7] Bariani P., Benuzzi, E. and Knight, W.A., 1987, Computer Aided Design of Multi-Stage Cold Forging Process: Load Peaks and Strain Distribution Evaluation, Annals of the CIRP, Vol. 36/1, pp.145-148.

[8] Sevenler, K., Raghupathi, P.S. and Altan T., 1987, Forming-Sequence Design for Multi-stage Cold Forging, J. of Mech. Working Tech., Vol.14, pp. 121-135.

[9] Lengyel, B., and Tay, M. L., 1988, Expert System in the Cold Forging of Steel, Proc. of the 27th Int. MATADOR Conf., pp.345-351.

[10] Bariani, P. and Knight, W.A., 1988, Computer-Aided Cold Forging Process Design: A Knowledge-Based System Approach to Forming Sequence Design, Annals of the CIRP, Vol.37/1,pp.243-246.

[11] Osakada, K., Kado, T. and Yang, G.B., 1988, Application of AI-Technique to Process Planning of Cold Forging, Annals of the CIRP, Vol.37/1,pp.239-2462.