A MULTIPLE APPROACH-BASED SYSTEM FOR PROCESS PLANNING IN COLD FORGING: some recent Developments and Applications

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1. INTRODUCTION

Some recent developments of a program for sequence planning of rotational cold forged components are presented. The work is one main task of the BRITE Project "Integrated CAD/CAE System for Application in Cold Extrusion" and is aimed at the development of an integrated computer-aided environment for engineering cold forged parts. In this project the authors have collaborated with process designers of one Italian (Teksid) and three German companies.
In this paper basic CAPP system categories are reviewed. In particular some limits of generative systems are highlighted to justify the approach presented, based on both automatic and iterative tools. Consequent upon the approach is the program architecture, which is discussed together with the main characteristics of the four modules composing the overall program. Afterwards, interactive process generation is described and functionalities available to generate new geometries are explained. At the end, some application examples are given.

2. A REVIEW OF COMPUTER-AIDED TECHNIQUES FOR PROCESS PLANNING

Manufacturing costs to produce a component should be as low as possible. This cheapness criterion is used to try forging sequences as it is usually more restrictive than that based on technological correctness. No tools are normally available to give information about sequence cheapness, as this property is strongly connected to a specific factory; as a conseguence, designers usually reason by similarities.
Whenever possible, expert designers use suitable sequences found in the company file as reference for planning new ones. Fig. 1 shows some results of an analysis aimed at determining procedures presently utilized at Tool Design Departments for planning sequences in cold forging. Results have been synthesized according to IDEF methodology. Two procedures are shown. The former is straightforward and is used when the component is very similar to another, the reference, already manufactured. In the most favourable circumstances minor geometry changes make the reference sequence suitable for the new component, otherwise the reference gives useful information for planning the new sequence. Depending on the amount of information extracted from the reference, other procedures can be defined for sequence planning.
Only when no reference is available in the company file, designers follow the latter procedure shown in Fig. 1. Designers must assume, for instance, a suitable number of forming stages, presses to be used, the billet diameter. Sequence design becomes in this case a much longer process composed of a number of activities, each one being an opportunity to verify the correctness of what previously assumed. The last test is the component production. This process may require several loops for changing precedent assumptions.

Two categories of CAPP systems exist to give a support to Tool Design Departments, which differs both as concerns difficulty of implementation and level of automation introduced in the above procedures. Variant CAPP systems group components into families according to similarities in the process plans, at each family being associated a standard plan and, in some cases, some ancillary information. Variant systems give a significant contribution improving performances of activity devoted to look for similar parts and in taking information from it, while they do not affect the other activities. The main reason of the success of the variant approach in process planning is its being based on the well-established reasoning by similarities. This approach does not change the way designers work, it simply make more systematic and fast information retrieval and still let the designer be responsible for the new sequences. As a consequence, variant CAPP systems are usually easily accepted at companies.
Based on a deeper knowledge of the technology and on use of more sophisticated tools, as Expert Systems (ESs), generative CAPP systems are aimed to introduce full automation in process planning activity. To meet designers requirements a generative system should be able to generate a cheap sequence. Basically there are two possible ways to satisfy this demand:

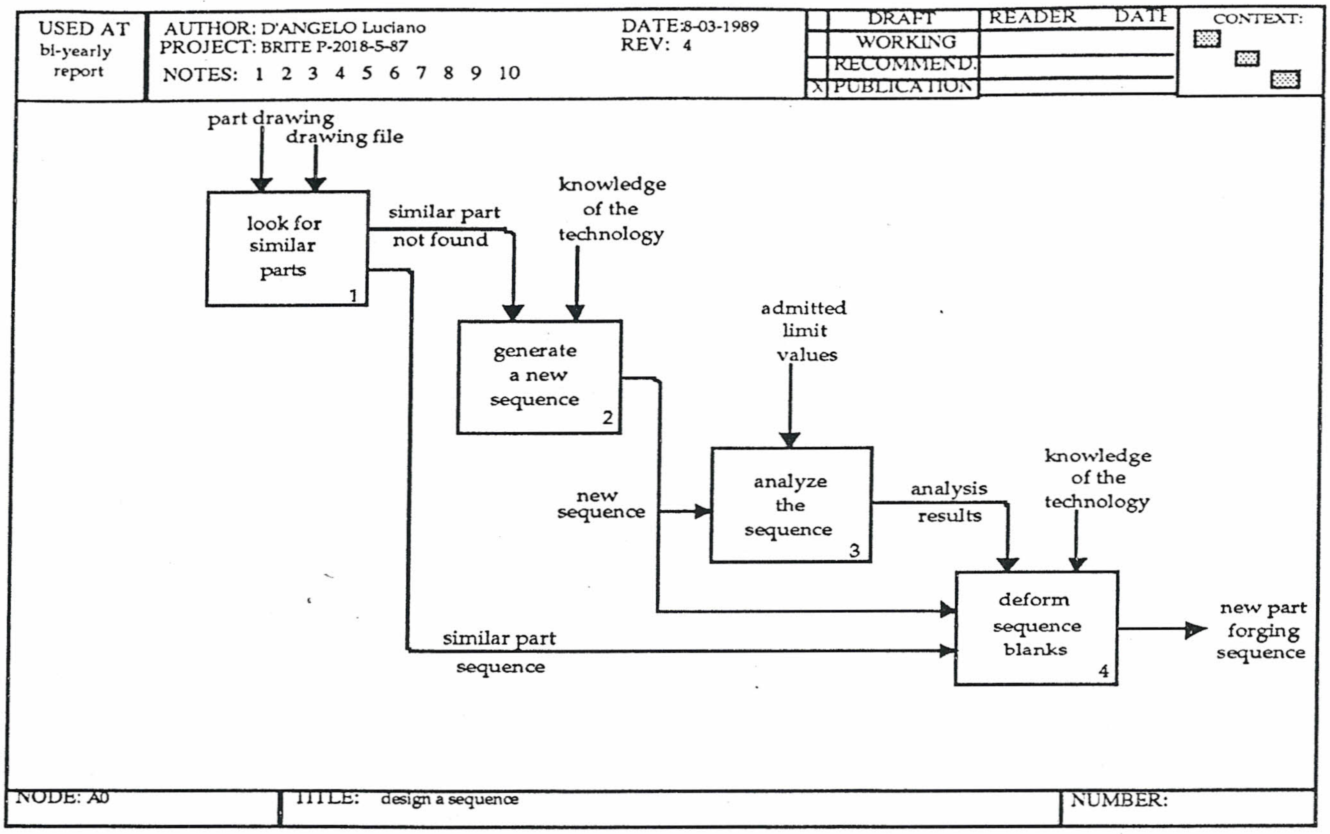

Fig. 1 - IDEF diagram of procedures for planning sequences in cold forging

- the CAPP system should contain the whole knowledge (information and data) necessary to generate cheap sequences, or
- the CAPP system should receive data from the manufacturing department or from simulation tools and be able to utilize them to improve sequences.

The latter way is, to some extent, preferable as it allows an easier adaptation of the system to modified conditions (new materials for tooling, new presses, etc.) and because the same CAPP system could be suitable for all companies. In fact, it is a consolidated idea that the knowledge required to design a correct and cheap forging sequence is not only related to the component features, but it heavily depends, mainly as concerns cheapness, also on a set of other variables related to the company:

- operating conditions (material and geometry of tooling, lubrication, ...),
- characteristics of the firm (available presses, tool maintenance management, cost structure, ...),
- others (batch size, yearly production, ...).

To overcome limits of the variant and generative approaches, researchers are working in two different ways. On one side systems being developed are still aimed at the full automation of planning activity by means of new tools, as neural nets and fuzzy logic ([1] and [2]). On the other, automatic tools are integrated with sequence editors used to modify geometries, as in the approach presented below and in [3].

3. Architecture of the Program

In designing the program architecture the above considerations have been taken into account. It was given up the idea of developing a fully automatic system, rather, a tool for improving Tool Design Departments efficiency. Accordingly, the program is made up of four modules, each one aimed at assisting the sequence designer in conducting one specific activity of sequence planning. Even where decision abilities are included, software is designed to be guided by designer. The four modules are devoted to:

- sequence retrieval,
- automatic generation,
- interactive generation, and
- sequence analysis.

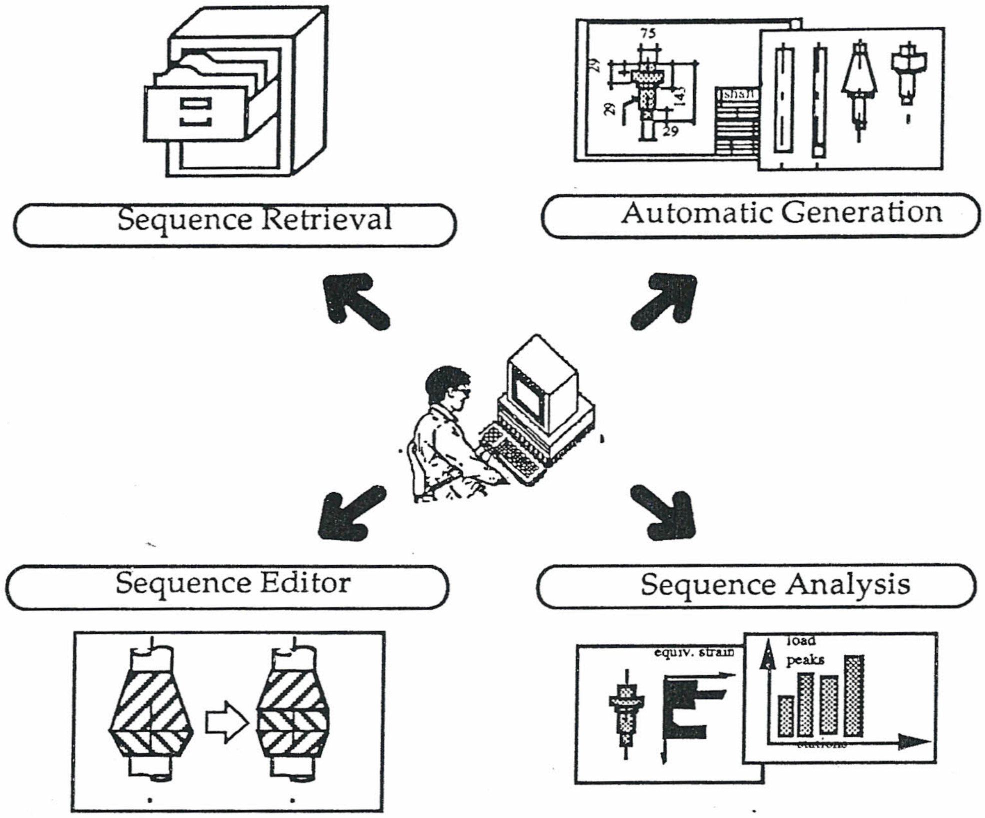

Fig. 2 - Program architecture

The above architecture, shown in Fig. 2, has been selected trying to keep unchanged procedures presently utilized at Tool Design Departments and already discussed in the previous paragraph.

Sequence Retrieval. Components already manufactured are grouped into families on the basis of similarities in the relevant forming sequences. According to Group Technology (GT) methodologies, a code is then associated to each family together with a standard process plan. When a new component is coded, a set of information is immediately available, useful for designing the relevant forming sequence:

- a range of diameters for billet selection,
- the most suitable presses in the job shop,
- the suggested number of forming stages, and
- forming operations order within the sequence.

The code is strictly dependent on the specific part profile of a company, on presses available in the shop, on know-how of the department. As a consequence, for each company a specific code should be developed.

Automatic Generation. The previous module is a typical application of variant CAPP. This one still uses a GT code for components, chiefly dependent on capabilities of cold forging technology, which gives information on range of diameters for billets and operation ordering within sequences. Information coming from component coding are utilized as input of sets of rules which make this module able of developing the whole forging sequence for a component. Whenever possible in the program, rules are parametric, so that they can be customized. As an example, the maximum upsetting ratio and the maximum reduction of area in extrusion are parameters.
The chosen approach, including both a GT code for sequence retrieval and rules for taking decisions, is classified, according to [4], as semigenerative. The only inputs required from user are the billet diameter and the number of forming stages. A more detailed description of this module has already been given in [5], [6] and [7].

Interactive Generator. Whichever module has been utilized, the one devoted to Sequence Retrieval or that for Automatic Generation, it is always necessary to edit a sequence for adjusting details as, for instance, adding fillets or changing diameters of extruded zones. This module offers several possibilities to alter geometries of blanks keeping volumes changes under control, as it will be described in the following paragraph. Beside, it is possible to to add new blanks in a sequence.

Sequence Analysis. In this environment producibility test is to be intended as an analytic evaluation of forging sequences. Obtainable results cannot be compared with those deriving from the most accurate analysis techniques. On the other side, this kind of analysis is much faster. This module make use of the same formulas normally utilized by designers for immediate verification of sequence correctness. It gives information about load- and work-peaks at each forming stage, together with the evaluation of the ideal component of strain accumulated in blanks. Besides, it is possible to simulate in any point of the sequence the insertion of annealings. More information on this module are available in [8].

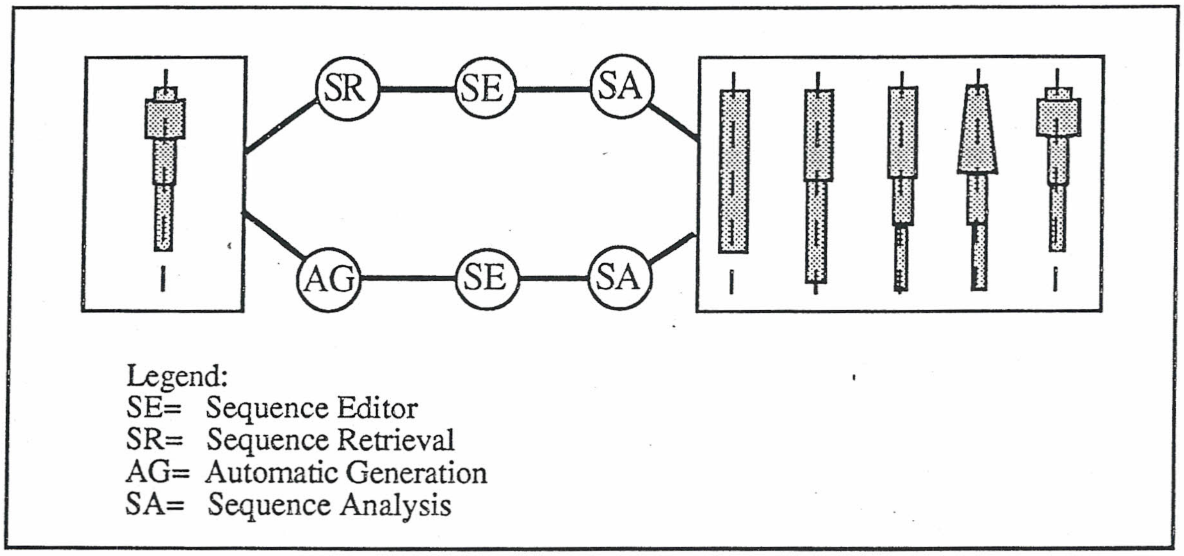

Fig. 3 - Expected usage of the four modules composing the program

The expected usage of the program is based on the procedures utilized by designers, as shown in Fig. 3. The first procedure is based on the variant approach. Information retrieved by means of the G.T. code are used to generate the new sequence with the editor. In some cases it is convenient to retrieve a stored sequence and modify it to have the new one, when the blanks of the two sequences have many dimensions in common, so that only minor changes of geometries are needed.
In the second procedure the automatic generator is used. The generation is expected to be guided by the designer, nevertheless in most cases it is necessary to edit the sequence, both before and after testing it.

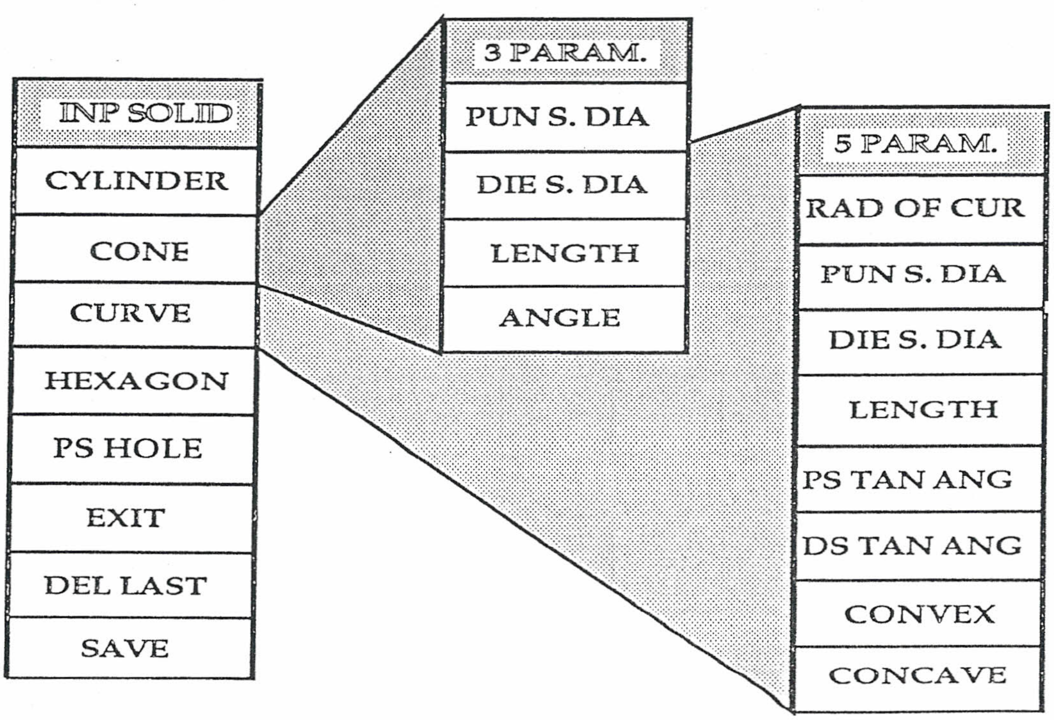

Fig. 4 - Structure of menus for input of geometries

4. Interactive Sequence Generation

Sequence generation begin with the input of the forged component geometry. Geometry description starts from the external profile, on the punch side. The profile is described as a pile of simple geometrical elements, cylinders, cones and curved elements. To make easier geometrical input starting from dimensions available on industrial drawings, for each kind of element all possible combinations of geometrical parameters (e.g., diameters, length, angles, radius of curvature) can be used. The same procedure is then used for input of geometry of punch-side and die-side holes. The structure of menus is shown in Fig. 4.

Besides, small curved elements can be inputted either as already described or as fillets. In the latter case they are added at the end of the input procedure. If the change of volume of the whole geometry is small, fillets are treated as secondary features of elements, else they are dealt with as elements.

When the geometry of the forged component is stored, the generation of the forging sequence can start. The first step is the selection of the billet. If the sequence is for a through-bore component, user is asked whether a through-bore billet is to be used.

Then a menu is shown which permits to examine available stock bars or to choose the billet diameter (2 diameters for through-bore), to evaluate the distribution of the ideal strain in the forged component or to calculate L/D ratio for the billet, based on volume of the forged component. The strain evaluation helps the designer, for instance, to balance deformation due to upsetting and extrusion operations. The L/D ratio must be over, to say, 0.8 for correct billet shearing, the limit being dependent on the designer habits and on the component material. If these tests do not satisfy the designer, a different billet can be chosen. Afterwards, if the billet is solid, the designer is asked whether he wants to press the billet at the first forming stage to make its end surfaces more regular. This operation is often added when billets should be used having a low value for the L/D ratio, namely for short components.

Fig. 5 shows the structure of the sequence editor. There are two ways to add an intermediate blanks. If it is very similar to one already in the sequence, it is possible to duplicate the existing geometry and then deform it using the tools described later on, otherwise the new geometry is inputted element by element as for the forged component. It is also possible to delete a blank from the sequence or calculate the volume difference between two blanks. Two other options allow to check geometry correctness: automatic dimensioning of blanks and the evaluation of ideal strain to transform one section of one blank into one section of another blank.

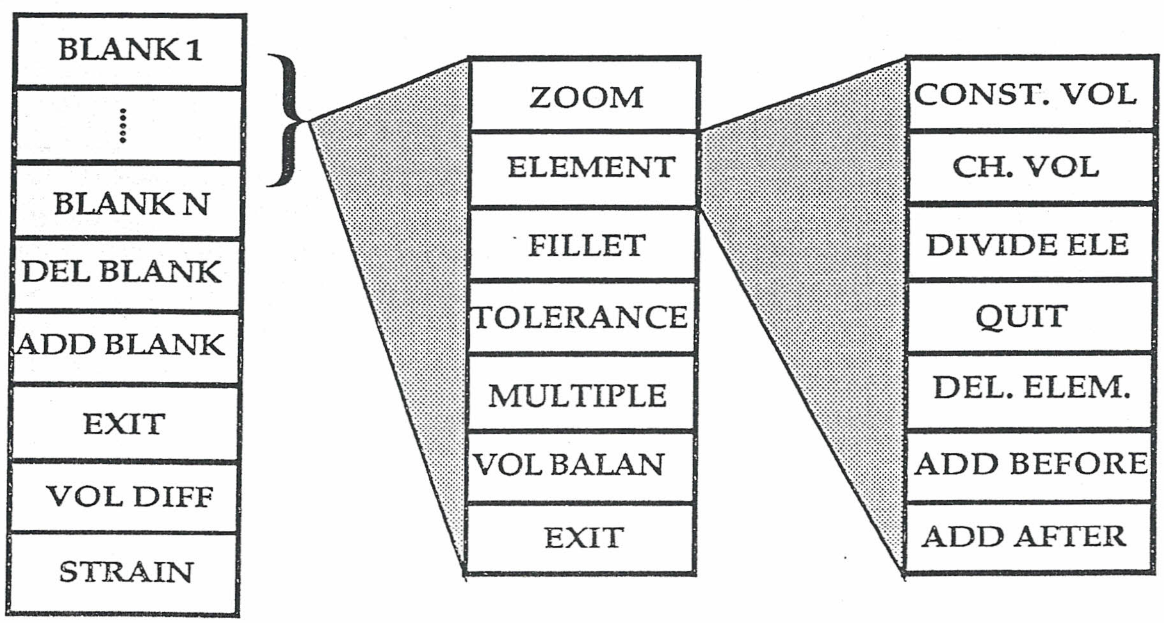

Fig. 5 - Structure of menus for Sequence editing

When the geometry of one blank is to be altered, it is possible to modify the geometry of one or more elements simultaneously, to add fillets, and to balance the blank volume with another blank.

If one element is chosen, several options are available:

(i) geometry change with constant or variable volume,
(ii) division of the element into two elements, with constant volume,
(iii) deletion of the element, and
(iv) addition of one new element at its punch- or die-side.

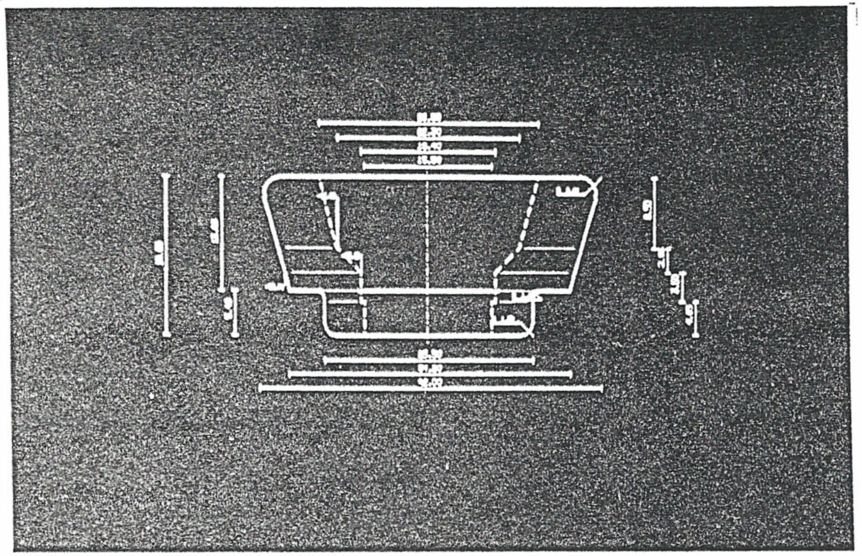

Fig. 6 A forged component for breaking system

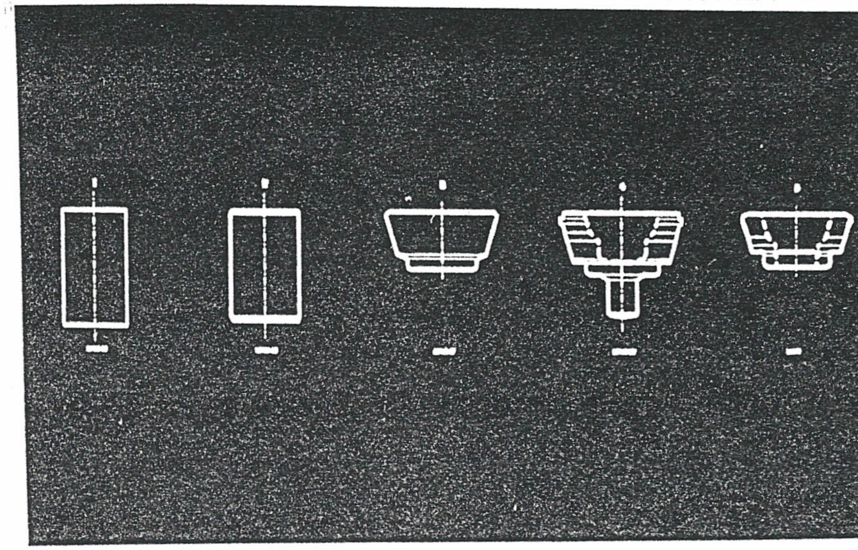

Fig. 7 The forging sequence

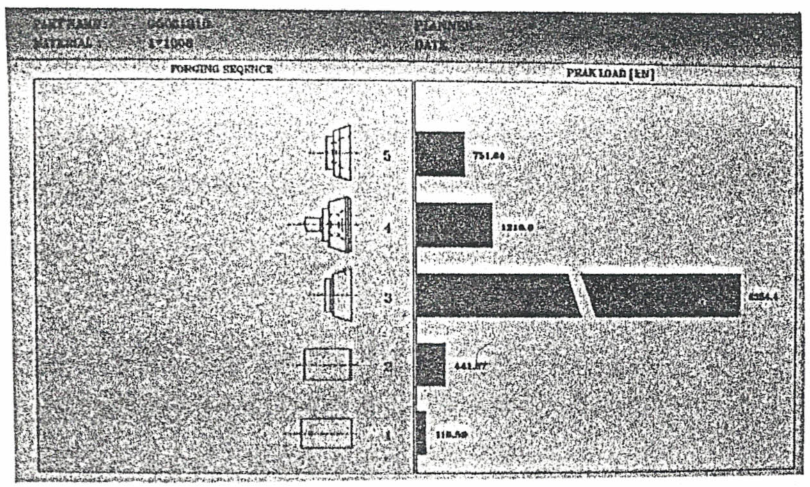

Fig. 8 Distribution of load-peaks for the above sequence

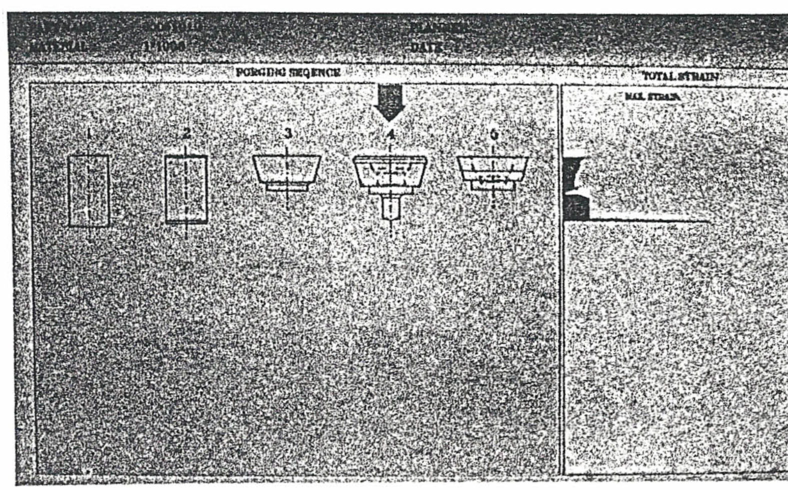

Fig. 9 Total strain accumulated at the fourth stage

Obtainable geometries are all possible combinations of cylinders, cones and curves (concave or convex) for inner and outer profiles, and solid profiles. For the input of hollow elements all the more often used combinations of geometrical parameters can be used, for the input of solid elements all the combinations are accepted.
Division of one element into two can take place fixing the following dimensions, referred to the new elements:

- (i) punch-side element length,
- (ii) die-side element length,
- (iii) punch-side element volume,
- (iv) die-side element volume,
- (v) intermediate external diameter,
- (vi) intermediate internal diameter.

If a group of elements is chosen, it must be decided whether the new elements are inputted starting from the punch- or the die-side, then the new geometry is inputted, element by element, the overall volume remaining the same.

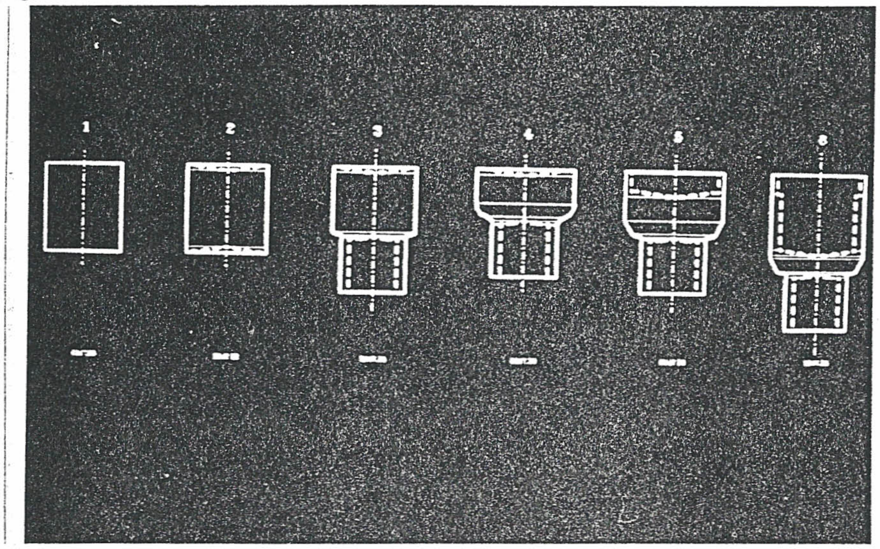

Fig. 10 The forging sequence for a valve housing

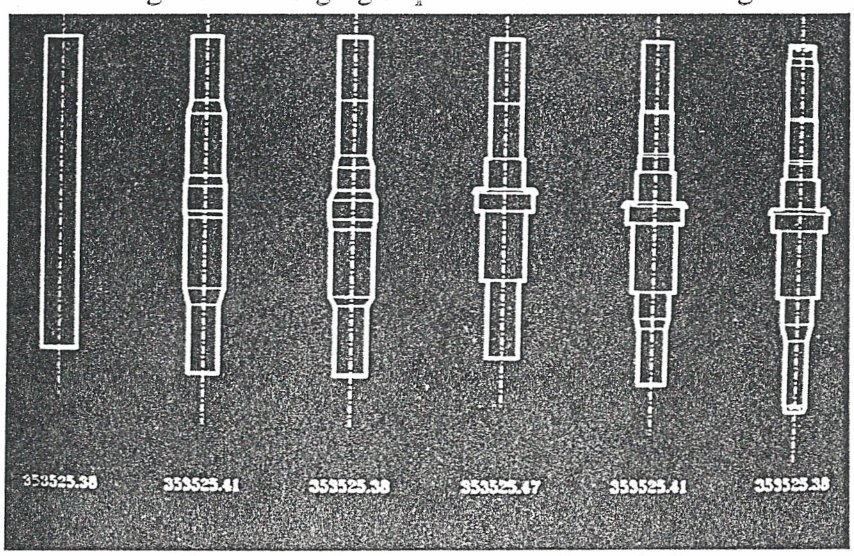

Fig. 11 The forging sequence for a shaft

5. Application Examples

In order to illustrate some capabilities of the program at the present stage of development, examples are given of the output obtained from generating and testing forging sequences for some components. Fig. 6 shows a forged component for breaking systems, dimensioned as it is shown by the program, for instance, to select the billet. One forging sequence for the component, developed using the program, is shown in Fig. 7.

The distribution of the load-peaks for the resulting sequence is shown in Fig. 9 , while in Fig 10 is the total strain accumulated at the fourth stage, as strain added at piercing and trimming stages can usually be neglected.
Two other sequences are shown in Figg. 10 and 11, respectively for a shaft of a car gear-box and for a valve housing.

6. CONCLUSIONS

The presented program is one module of an integrated CAD/CAE system which covers all the main activities of product engineering for cold forging technology.

Variant and Generative CAPP systems have been reviewed. Variant CAPP systems can automate only few activities of sequence planning procedures; on the other side, generative systems are, to some extent, more powerful but lack at the moment in ability of designing cheap sequences and of taking account of information coming from the manufacturing process and from manufacturing simulations. The approach presented in this paper integrate variant and generative systems with a sequence editor to overcome limits of the two categories of CAPP systems. The program has been tested with a large number of sequences coming from the four companies with which authors have collaborated, and some examples are given in the paper.

7. ACKNOWLEDGEMENTS

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