Tool Cost Estimating at the Early Stages of Cold Forging Process Design

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Identifying the most appropriate sequence of cold forging operations for a new part requires a number of technological and economical evaluations concerning loads, mechanical properties of the forged component, its producibility on the machines as well as costs for equipment and associate tooling.

This paper presents a methodology for estimating initial and maintenance costs for cold forging tools. This methodology is for use of planners at the early stages of process design, when the sequence of forging operations and equipment are decided and before details of the tooling system are available.

KEY WORDS : Tool, Cost Estimating, Cold Forging.

1.0 INTRODUCTION

Tools represent together with material and equipment utilisation the main cost drivers in cold forging.

Tooling costs have a profound effect on the cold forging process economy. Capitals invested in tooling are usually high and often much higher than investment in equipment.
The relatively high initial costs of tools tend to restrict cold forging economically to large quantity production, where costs for tool maintenance and replacement become the dominant costs. In Fig.1 the costs for initial tooling, machine setting-up and maintenance for a typical cold forged component are compared for different batch sizes.
Moreover, efficient management in the forging shop extended to the tooling system, when combined with appropriate tool maintenance strategies, can lead to significant reduction of production costs [1 - 2].

Accordingly, realistic estimates of costs for tooling are essential to an economically sound process design, especially at the stage of forging operation sequence design. The design of a forging sequence is, in fact, the most critical responsibility in planning a multi-stage cold forging process. It directly influences all the other decisions required before the workplanning is completed.

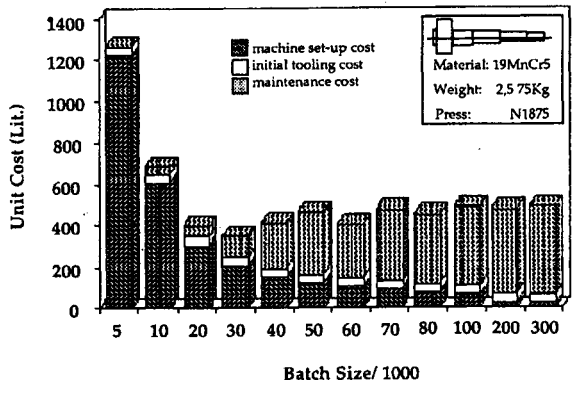

Fig. 1. Costs for initial tooling, machine set-up and maintenance for a typical cold forged part.

Same detailed cost analysis procedures for cold forging have been developed previously [3 - 4]. Like conventional tool cost estimating methods, they are meant to be applied after the tooling system has been detailed. Therefore, they appear inadequate to compare the several alternatives sequences and strategies that can be proposed for a new component at the early stages of process design.
The main problem is that a generic part can be produced through using several different number of forging steps and process combination. Using a short sequence, with several combined operations, may involve a certain amount of risk and possibly result in reduced life of some tool components. However, if the total quantity of forging required is relatively small the use of a short sequence may be the most economic. Use of a longer manufacturing sequence will increase initial tooling costs and machine time, but may increase the life of individual tool components, although the extent of this increased life may be difficult to estimate. For large production volumes the strategy of using a longer manufacturing sequence may be the most economic, as tool replacement costs will then dominate the tool cost per part.
These type of strategies are difficult to incorporate into conventional cost procedures.

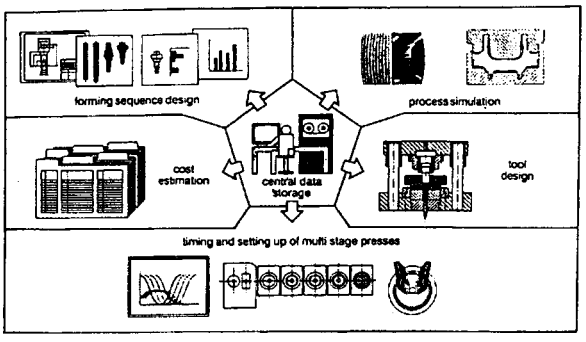

Fig. 1. Structure of the itegrated CAD/CAE system for the cold forging technology

This paper presents some progress in developing a set of procedures for obtaining realistic but simplified estimates of initial and maintenance costs for cold forging tools. These procedures are based on simplified cost models and are intended to be used at the early design stages of the forging process, when the forging sequence and equipment are decided and *before* details of the tooling system are available. They are incorporated in a software tool for use by process designers in designing the forging sequence and selecting the appropriate equipment.

The work described in this paper is part of a research project aimed at developing an integrated CAD/CAE system for cold forging technology (Fig. 2), sponsored by the BRITE programme of the European Communities and with the collaboration of research institutes and industry.

Four tool cost estimating procedures are presented and discussed. They are devoted to cost estimating for initial tooling as well as maintenance and replacement, with particular emphasis on tooling systems for general-purpose multi-station transfer machines.
The approach is based on data from machine-tool manufacturers and the toolmaking department of a forging company.

2. INITIAL COSTS FOR TOOLING

Normally regarded as fixed production costs, the costs for the initial tooling system necessary to produce a new forged part are determined by:

tool-material costs, and
labour content of tool fabrication,

the latter contribution including man hours for machining, grinding, polishing, fitting and assembly of tool components.

Keeping these costs as low as possible –through, for instance, a reduced number of forging steps and use of standard tool components or shortening of time for tool design and manufacture– is of very great importance for competitiveness of the cold forging technology, especially in small quantity production.

In the complete set of tools filling recesses at the punch- and die-side of presses, three categories of tool components can be usually distinguished [5]:

- *basic tooling system components*, such as housings and pressure pads, that are utilised in several configurations of the tooling system,

- *tool configuration components*, that, fixing –for instance– outer dimensions of punch head and type of ejectors, are intermediate between the basic tooling system components and the
- *product-specific tool wear components*, such as punches, die inserts and ejectors, that are in direct contact with the workpiece material.

In the module for production cost estimating of the software system of Fig. 2, two separated procedures can be used to evaluate initial costs for tooling. They are devoted, respectively, to:

- early assessment of material and fabrication costs for the overall tooling system, including all three categories of tool components, and
- early assessment of costs for manufacture of individual tool components.

The two procedures, together with relevant approaches and underlying assumptions, are presented in the rest of this section.

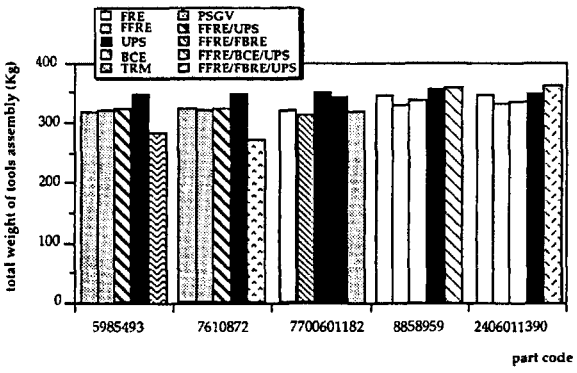

Fig. 3. Total weight of tool components at each station for five typical parts.

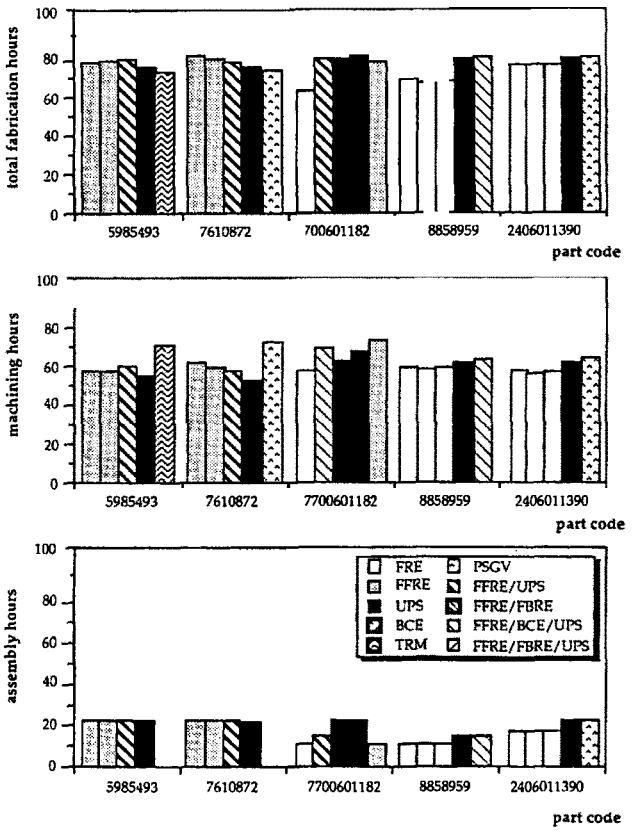

Fig. 4. Total manufacturing hours for each station of five typical parts.

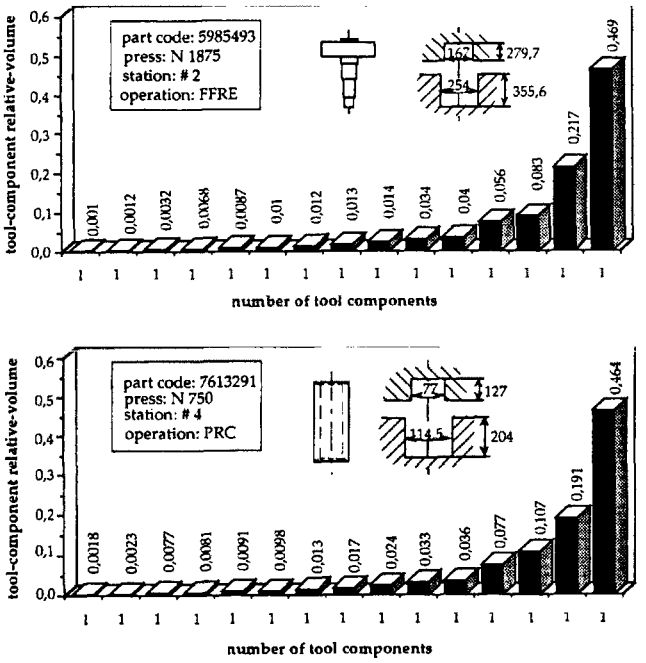

Fig. 5. Tool elements distribution at the station of two different transfer presses.

2.1 Cost Estimating of the Overall Tooling System

A significant finding of the analysis carried out by the authors [6] is that tool material and tool fabrication costs *per station* on a particular press are substantially constant and independent of the operation being performed at each station.

This can be confirmed by the typical results given in Figs. 3 and 4 which show, respectively, the total weight of tool components at each stations for typical multi-station machines and the tool manufacturing hours for each stations.

The main reasons for this result is that each press station on a particular machine has a standard recess of a fixed volume for the tooling and this space is filled with substantially the same distribution of tool elements, independently of the operation performed. Fig. 5 shows very similar distributions of the tool elements at the stations of two transfer presses, with different size and equipped to produce parts with different shape through different sequence of operations.

Thus, in order to estimate initial costs for the overall tooling system a data base entry for the selected machine of the tool material cost per station and the tool fabrication time per station can be utilised, independent of the operations performed, to a high degree of accuracy. The tool cost per product, for initial tooling, is then obtained by dividing the total initial tooling cost by the total volume of parts to be produced.

2.2 Cost Estimating for Individual Tool Components

This second procedure permits evaluating the manufacture costs of the tooling system *element by element*. It is particularly suitable to early assessment of costs for the few tool wear components of the tooling system which are specific to the actual forged product and that normally represent the real capital investment for tools accounted for a particular product.

The approach on which the cost estimating method is based is fairly simple. The tool elements are classified according to function, shape and material. Then, for each class, cost to manufacture an individual tool element is calculated as a function of its size.

Classification of tool elements revealed particularly effective for the cost estimating purpose [7]. Most of the tool components pertaining to the same class are, in fact, rotational parts with very similar shape and processing steps in their manufacture involve very little secondary machining.
This is illustrated by the data shown in Fig. 6 for a typical forging (a stepped shaft), which shows the tool components classified by the

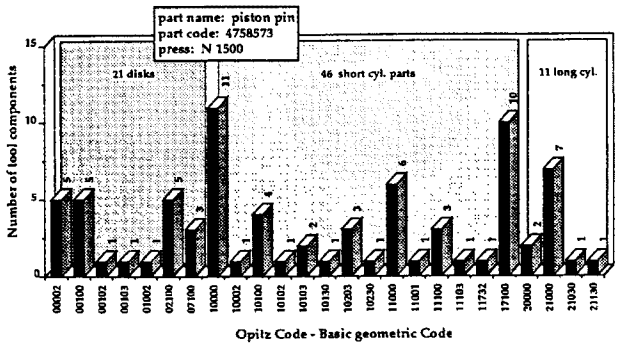

Fig. 6. Tool components classified by the Opitz classification system.

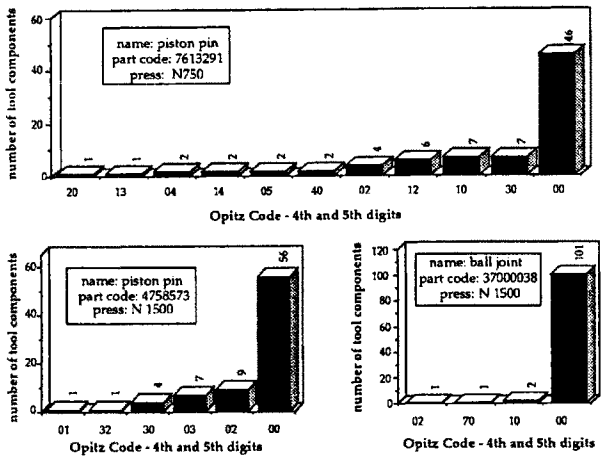

Fig. 7. The Opitz code 4th and 5th digit value.

Opitz classification system [8]. Fig. 7 further shows for these typical components the distribution of the Opitz-code fourth and fifth digit values, which indicate features produced by secondary machining.
For classes of parts that share so closely shape and manufacture attributes, the size of the finished part (its volume or weight) is strongly correlated to the costs for its machining and grinding [9 - 10].

According to this, the cost-per-unit-weight for manufacture an individual tool component C_{uit} is obtained as:

$$C_{uit} = A w^{B} \qquad (1)$$

where w is the weight of the finished tool component and A and B are two coefficients calculated for each class of tools.
Fig. 8 shows equation (1) calculated for a class of punches.

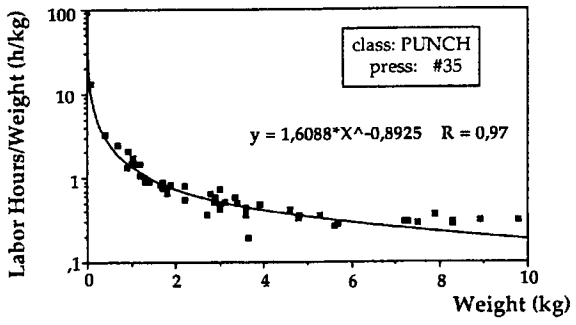

Fig. 8. Cost per unit weight for manufacture a class of punches vs the finish part weight.

3. Costs for Tool Replacement and Maintenance

Costs for tool replacement and maintenance are typical variable production costs. They become the dominant costs, when compared with costs for the initial tooling and the machine setting-up, in large quantity production and high batch size (Fig. 1).

These costs are incurred each time an element of the tooling system has to be replaced. They include:

- cost for the downtime of the press,
- costs for manufacturing, reworking or refurbishing the replaced tool element, and
- costs of tool pre- and post-operative handling and assembly.

The service time of tool elements, together with the maintenance policy, determine the frequency by which the three costs are activated.
In the module for production cost calculation which is part of the software system of Fig. 2, two different procedures are available to assist the user in evaluating the influence of maintenance policy and service life of tool elements on maintenance and replacement costs. These two procedures are devoted, respectively, to:

- evaluation and comparison of alternative strategies for management and maintenance of the tooling system, and
- approximate evaluation of costs for maintenance and replacement of tool elements.

3.1 Evaluation of Tool Maintenance Policy

Cold forging machines and, especially, general-purpose multi-station presses normally represent, together with the tooling system, a fairly high capital investment for firms. Keeping this equipment in operation as much of the time as possible is the main objective of a tool maintenance policy. An appropriate program in maintaining the tooling system can, in fact, greatly reduce the costs of machine down-time and tool replacement.

The procedure for evaluation of tool maintenance policy has been developed to assist the user in developing, analysing and comparing tool maintenance policies in order to design the most favourable program for maintenance of the system consisting of the machines and the relevant tooling.

This procedure is based on a simulation model that has been developed using SIMSCRIPT II.5 [11] discrete event simulation language.

Distribution of the service life for most of tool components is required as input data. To this end, definitive data collected for a number of parts forged on the same set of machines allows for the calculation of distribution parameters [12 - 13]. A maintenance policy represents, in fact, an organisational choice that is not specific to a product but normally extends to a class of products and relevant machines or to the entire forging shop.

The performances of the press-tooling system that can be expected from a particular policy are measured in terms of total machine downtime, unit maintenance costs per machine and per station as well as contributions to unit costs from tool replacement, assembly and machine downtime.
Examples of the program output are given in Figs. 9, 10 and 11, all of them referring to a steel stepped shaft processed on a 5-station transfer machine. Fig. 9 shows the growth of the unit maintenance costs and the unit costs per station during the production of the batch, when a failure-based maintenance program is applied. The different contributions of the downtime of the press, the manufacture of replaced tools and their handling and assembly are illustrated in Fig. 10. In Fig. 11 the failure-based maintenance program is compared with two different preventive-maintenance programs. Savings achievable from a regular tool replacement are evident.

3.2 Assessment of Costs for Tool Maintenance and Replacement

When a maintenance policy has been decided, costs for tool maintenance and replacement can be evaluated in a realistic but simplified manner by using a procedure based on an analytical approach.
Maintenance costs per part and per machine-station are calculated in a practical way. The "critical" stages in the proposed forging sequence can be identified immediately and the effect of changes in the service life of tool components can be evaluated easily.
A typical output of the program is shown in Fig. 12, where unit maintenance costs are calculated and compared for two different service lives of a punch at the forth stage of a 5-station transfer machine.

Average values of the service life of tool components are required as input data. However, these values have to be specified only for a few tool elements (normally one or two per station) which are in contact with the part material during forming and with an expected service life less than the batch size.

Indications on service lives are retrieved from a data base where life data of tool components are systematically collected and classified according to parameters which are specific for the tool components (such as tool geometry, manufacture, etc.) and application (such as loads, lubrication, etc.) [14].

4. Concluding Remarks

A set of procedures have been presented for estimating initial and maintenance costs for cold forging tools. These procedure are for use of designers at the early stages of process design, when the sequence of forging operations and equipment are decided and details of the tooling system are not yet available.

These estimating procedures are included in a module for production cost calculation which is part of an integrated CAD/CAE system for cold forging technology.

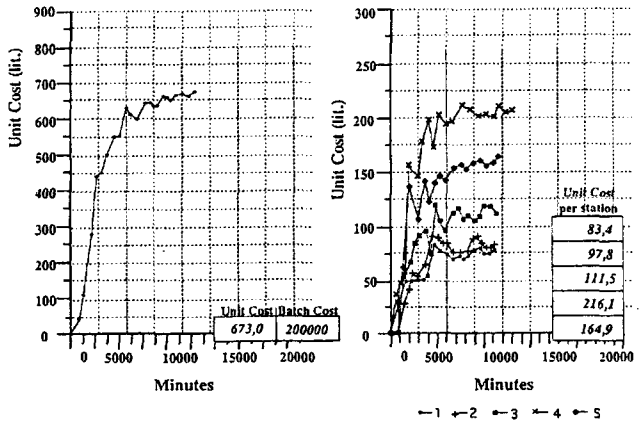

Fig. 9. Unit maintenance costs during batch production.

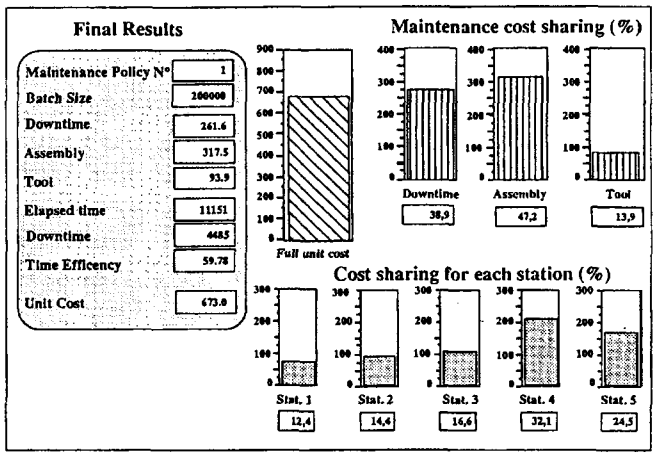

Fig. 10. Unit maintenance costs due to downtime of the press, manufacture of replaced tools and their assembly.

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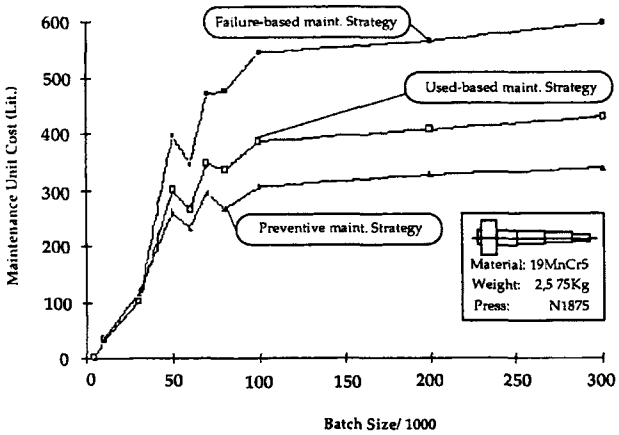

Fig. 11. Comparison of three different tool-maintenance strategies on a 5-station transfer machine.

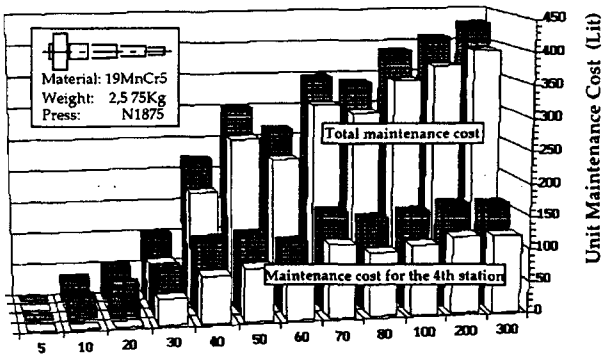

Fig. 12. Mainteance-cost reduction as a consequence of the increase of life from 6,000 to 18,000 parts for a punch at the 4th station.

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