An Integrated Approach in Design Tooling, Setting Up and Timing of Forging Transfer-Machines

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Abstract

Multi-station forging machines with automatic work transfer between stations permit very high production rates to be reached, but considerable time and effort by skilled personnel must be spent in workplanning and their setting up and timing.
The paper presents an integrated approach to the computer-assisted design of the tooling systems and identification of appropriate setting conditions and timing for multi-station presses to be used in cold, warm and hot forging.
The approach is based on (i) the classification of possible configurations of punch- and die-side tool subassemblies, (ii) the automatic retrieval of the tool-holder assembly configuration for the specific station of the press, (iii) the assembly rules and automatic scaling and fitting of individual tool components and (iv) the animation -with check for interference- of die, punches, slugs, grippers and ejectors according to the kinematic model of the press.

Keywords: forging, tooling, press

1. Introduction

Multi-station general-purpose machines with automatic transfer between stations (hereafter called *transfer-machines* or *transfer-presses*) permit very high production rates to be reached. They are traditionally used for large quantity production (such as the manufacture of automobile parts), however, thanks to additional advantages introduced by modern versions, such as higher and more stable quality and precision of the forged product and increased flexibility, transfer machines are going to be suitably used also on moderate to low production volumes [2, 11, 14].
Due to the complexity of the operations performed by these machines, a considerable time and effort by skilled personnel must be spent in their workplanning and setting up, that include activities such as designing the tooling system and the handling devices and planning the complete co-ordination of the workstation actions with the handling and transferring system (hereafter called *timing*).

Extensive work on various aspects of planning forging processes for transfer presses is being conducted in various countries, notably in the US [19], Germany [15, 18], Japan [12], South Korea [17] and Italy [1, 3]. Most of applications are in cold forging and relate to specific workplanning tasks, such as designing and evaluating the forging sequence [4, 20], designing the tooling system, with particular emphasis on the die cavity geometry [16], and the machine timing [5].

Designing the tooling system for a transfer-machine must be considered, likewise designing the handling devices and the timing, a machine-specific activity because the machine sets numerous and heavy constraints to size and configuration of tooling assemblies and, consequently, to the preform sequence. In addition to the number of forging stations and maximum peak loads (combined and per-station), main machine constraints include an even and symmetric distribution of load peaks at the different stations, maximum shearing load, die spacing, size and shape of die-side and punch-side ejectors, maximum diameter and length of slugs for handling and transferring by grippers. Sometimes, constraints from the handling and transferring system do not permit a correct timing to be achieved and partial redesign of tools or complete revision of the preform sequence may be required [6, 7].

On these bases, an approach has been developed by the authors for the computer-assisted workplanning of transfer machines for cold, warm and hot forging tasks that integrates the design of the tooling system and handling devices with the complete timing and setting up of the machine. Based on this approach, a prototype computer-aided system has been developed in the frame of a European EUREKA-FAMOS research project. The prototype is presently utilised by the forging organisations participating in the project.
The paper is mainly focused on the approach. The prototype system is shortly outlined in the second part of the paper together with an illustrative example.

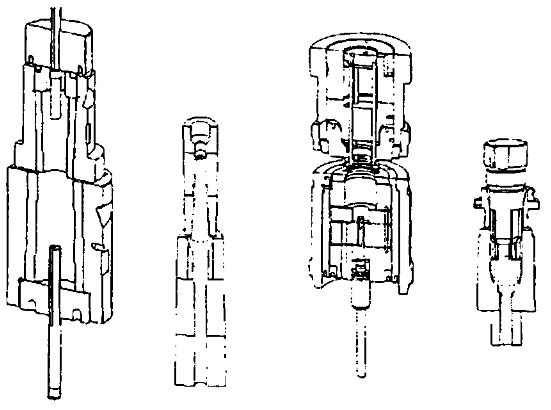
2. The Approach

Basic Assumptions

The basic general assumption underlying the proposed approach is that all the machine-specific activities for the workplanning of transfer presses are more advantageously carried out when they are integrated in a unique CAD-based environment. Major benefits expected from this approach are (i) removing from the shop-floor and integrating with the process design a large part of the work concerning the producibility check of the forged product and the machine preparation and (ii) a reduced time to produce a complete workplanning of the machine.

Design of the Tooling System

For the tool design purposes, the tool assembly at the stations of a transfer press are regarded as consisting of two couples of main subassemblies (Fig. 1).
The first couple is made of *the punch-side and the die-side tool holders*. They comprise two categories of tool components: (i) the *basic tool parts* (e.g. pressure pads, housings, etc.), which are independent of both the forging



(1a) (1b) (2a) (2b)

Fig. 1 Tool-holders (a) and tool-cores (b) for cold (1) and warm (2) forgings on multi-stage presses

operation and the specific geometry of the slug at that station, and (ii) the *process-specific tool parts* (e.g. ejectors, counterpunches, etc.), that depend on the particular forging operation but are still independent of the specific geometry of the slug [8, 12, 17]. Accordingly, tool holders can be grouped into families that share the same combination of attributes, such as the press, the forging operation and the general shape of the slug.

The second couple of main subassemblies consists of the *punch-side* and the *die-side tool cores*, that comprise the tool parts contacting the blank and vary with its specific geometry.

On the basis of this distinction, the design of tool holders can be automatically retrieved from a machine-specific database, whereas tool cores can be generated by using assembly rules and automatic scaling and fitting of parts from a library of standard parametric tools.
The retrieval-based procedure for tool-holders design forms the basis for a systematic procedure that enables the planner experience to be incorporated in a formalised manner and, at the same time, the set of toolings for a specific machine to be substantially rationalised with a great cost saving [9].

Design of the Machine Timing

The basic idea underlying the approach to the computer-assisted timing of transfer machines is that of performing all the timing tasks by using a *virtual* machine. Following procedures that are common to most of transfer machines, collision-free timing can be easily achieved in a minimum number of try-outs.
The mathematical model of the machine must be capable of simulating its operating in the workstation areas and, in particular, the configuration of the workstation components (blanks, punches, dies, ejectors) and the transfer system (grippers) corresponding to input values of the pressram stroke or the crankshaft angle. The model is derived from the travel-diagrams of the machine that are currently used by workplanners and machine operators to perform the timing. These diagrams (examples are given in Fig. 2 for a 1600 tons 5-station vertical machine) give for each object moving in the working area (punches, ejectors, grippers) a family of curves, each family describing the position of the object as a function of the machine crankshaft angle and of an adjusting parameter.
A general representation of these diagrams, suitable for every class of transfer presses, is based on a piecewise polynomial approximation.

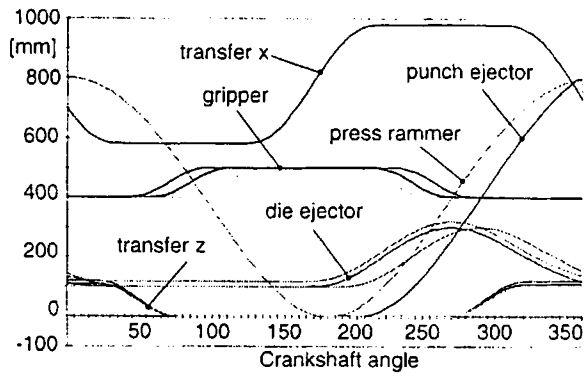


Fig. 2 Travel-time diagrams for a multistage press

3. Outline of the System and Illustrative Example

The functional architecture of the system is shown in Fig. 3. The system consists of four modules that are devoted respectively to (i) slug coding for tool-assemblies retrieval, (ii) generating the CAD commands for setting the specific CAD environment, (iii) generating tool assembly design for the workstation and (iv) performing the complete timing of the machine. The first and the second modules work outside the CAD environment and are developed using a CGI (Common Gateway Interface) protocol. The third and the fourth are integrated into the CAD system and utilise its internal programmable functions.

The main activities carried out inside the four modules are shortly described in the following of this section. The illustrative example refers to the first warm forging stage of a CV-joint (the forging sequence is shown in Fig. 4) processed on the 1600 tons 5-stations vertical press whose travel-time diagrams are in Fig. 2.

In the first module the slug is classified according to four attributes: the chosen press, the functional class of the part, the shape of the slug (classified according to an extension of Wagener classification to include non-rotational parts) and the forming operations carried out at the punch- and die-side [7].
For the slug indicated in Fig. 4 (first station), the generated code is, as follows:

11 ST_325_D41_P02

press code
forged component code
slug shape code
die-side operation code
punch-side operation code

The search, through the new code, into the database of already existing codes, can lead to two cases:

(i) complete matching of the code with an existing one,
(ii) matching restricted to some of the attributes.

In the case (i), a tool set exists in the CAD database that suits the current workstation. The entire tool set will be retrieved needing only marginal adaptations of the tool core subassemblies.
In the case (ii), all the tool holder subassemblies available for the specific press will be retrieved according to individual or combined attributes.

In the second module the CAD commands for setting the specific CAD environment to the tool design and machine timing tasks are automatically generated. Most of these commands relate to the configuration of the CAD system and create the common references for tool assemblies and slugs.

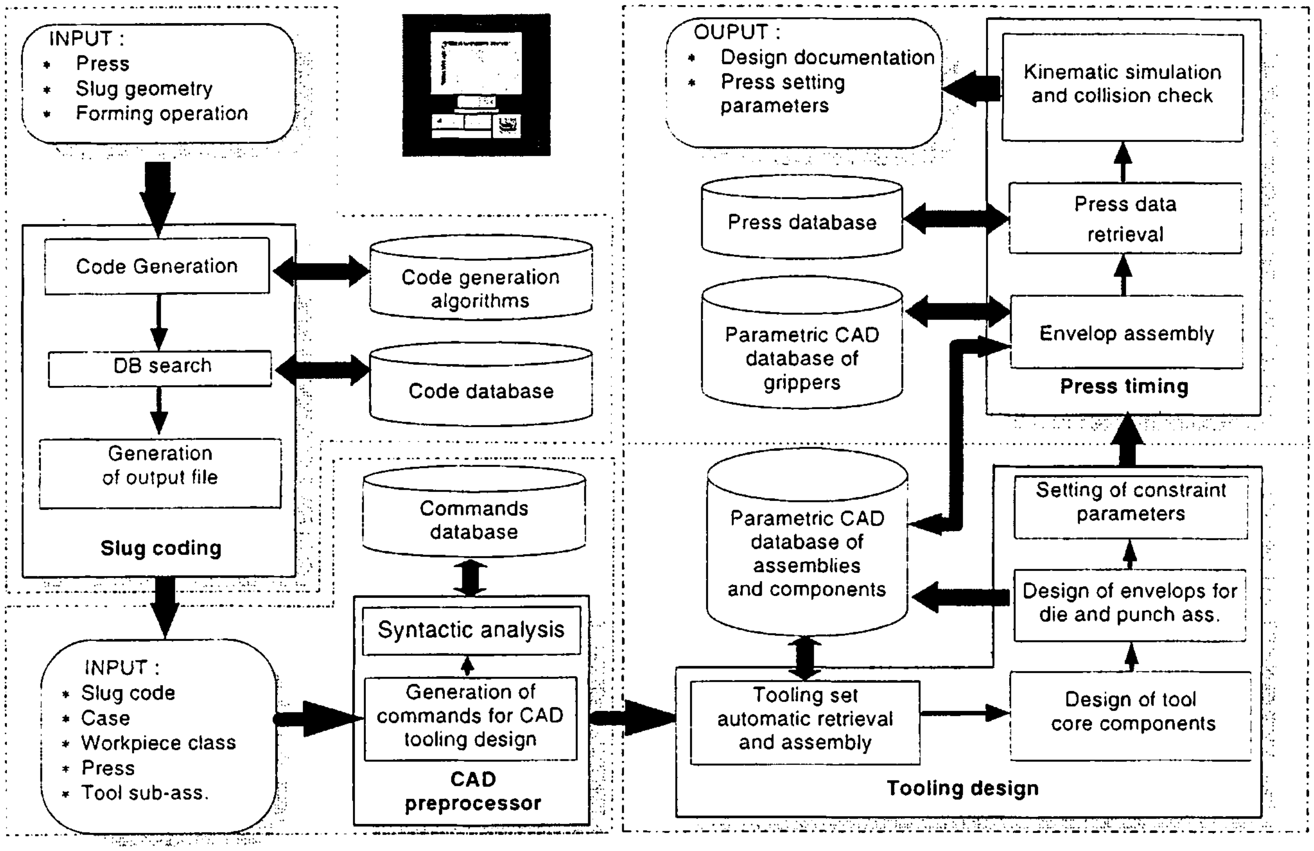


Fig. 3 Functional architecture of the system

In the third module the commands previously generated are automatically executed and the entire tool set (case (i)) or the punch- and die-side tool holders (case (ii)) are retrieved from DB. In the case (ii) tool core components are generated from the relevant library. The necessary scaling and fitting are automatically performed as well.
Fig. 5 refers to case (ii) and shows the slug, the generated tool assembly and the entire tool set.
Last activity performed by this module is that of generating the envelops of the punch, the die and the ejectors.

The fourth module is devoted to the timing of the press. The three major components of the module are the machine database (where the complete mathematical model of the machines are stored, including travel-time diagrams), the gripper database and the motion and collision-check engine. Activities performed by the engine include the CAD environment configuration for the timing purposes, the retrieval of the 3D solid models that participate in the animation of the workstation areas (envelops, fingers and slugs), the animation and the collision check. Figs. 6 and 7 show the CAD environment at the beginning of the timing session and at three different stages during the animation.

4. Concluding Remarks

An approach has been presented for computer-assisted workplanning of transfer machines for cold, warm and hot forging tasks.
The approach has formed the basis for the development of a prototype computer-assisted system that integrates the design of the tooling system and handling devices with the complete timing and setting up of transfer presses.
The approach leads to a number of improved methods including:

(i) rationalised and systematic procedures with more consistent design of tool assemblies,
(ii) timing procedures that integrate in a computer-assisted workplanning environment large part of the timing and setting up that are traditionally performed in the shop floor,
(iii) tool design and machine timing performed more rapidly and efficiently,
(iv) complete producibility check of forgings and complete workplanning of machines.

5. Acknowledgements

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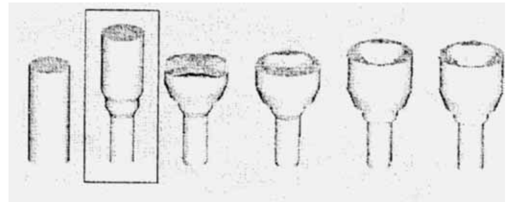

Fig. 4 Warm forging sequence of a CV-joint

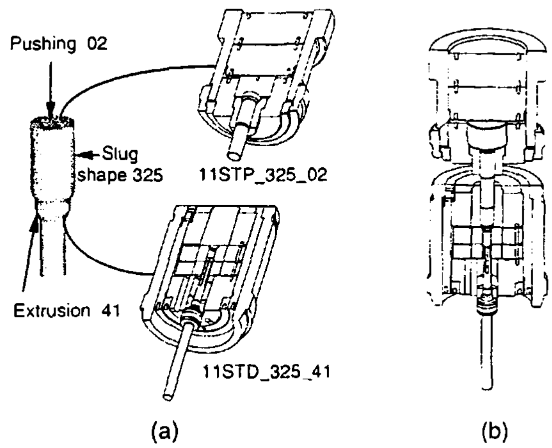

Fig. 5 The slug and tool assemblies with relevant cores (a) and the complete tool set (b)

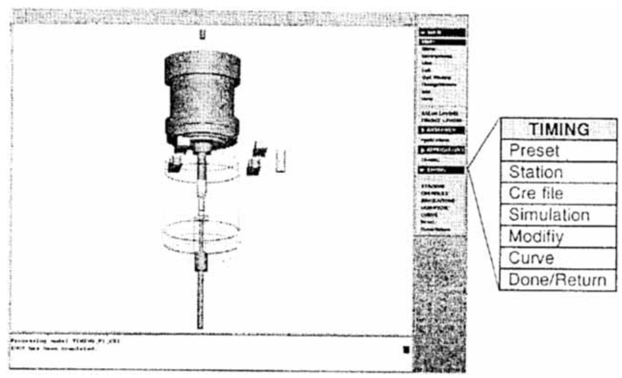

Fig. 6 The CAD environment at the beginning of the timing session

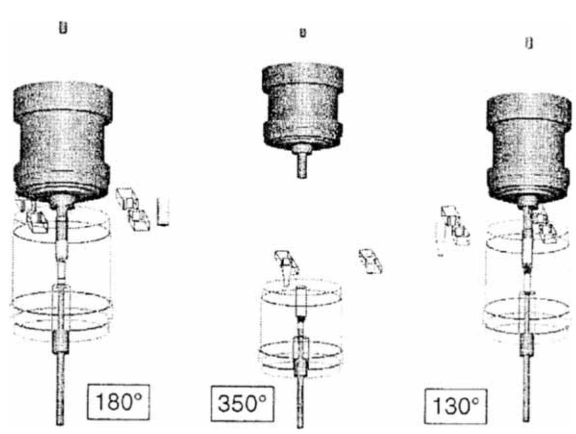

Fig. 7 Three different stages during the animation