"Virtual Set-up of Multi-stage Presses Integrated with the Design of the Forging Process "

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Abstract

In the current practice the set-up of multi-stage transfer presses results to be an intensive-labour and time-consuming activity which considerably contributes to the increase of non operational time of the press. Considering the high production rates of these machines when equipped with automatic transfer devices, as well as the high investments for equipment and tooling, a reduction of non operational time of the press can lead to an appreciable increase of production efficiency.
A Virtual Environment has been developed and implemented for the design and test of the forging process. It consists of a set of software modules specifically devoted to assist the process designer in a set of tasks including (i) design of the forging sequence, (ii) design of components and assembly of the tooling system, and (iii) timing and setting up of the press.
By this approach, the setting up of a press is moved from the operative level of the shop floor to the more decisional level of process planning, where preforms and tooling are designed.
The present paper is focused on the module for timing and setting up of the press. This module assists the process designer in the off-line determination of press parameters for a specific forging task. It is based on 3D parametric models of the objects and their animation in the working area of the press according to the kinematics of the machine. It allows a correct timing of movements of punches, ejectors, grippers and blanks without collisions and blank dropping.
The virtual set-up has been applied in industrial environment and has demonstrated advantages summarised as follows: (i) easy generation and test of alternative sets of adjustment parameters, (ii) reduction of modifications of the tooling system, and (iii) considerable reduction of the time for setting up and timing of the press and, therefore, of the total lead time to manufacture.

The multi-stage press timing and setting up are considered as a time consuming works in forging processing planning, especially it operates in the workshop which makes non-operational contribution. To minimise the operation will increase the production efficiency. Using computer to aid the processing planning is promoted to solve the problems. This paper presents a 3D module which is integrated into a parametric CAD/CAE system with the tooling design system together. The module makes it possible to simulate and animate the forging operation movements according to the press moving rule curve diagram. The collisions among the different parts, (slugs, grippers, ejectors, punch and die), can be verified. The trail-and-error procedure is utilised for correcting the press setting up by modifying the certain parameters of the curves and components dimensions. Using the parameters created by the timing module, the press setting up time will be reduced a lot.

1. Introduction

Modern multi-stage forging machines, with automatic mechanical transfer between stations, permit very high production rates to be reached which have been widely used in cold and warm automobile forging industry (fig. 1).

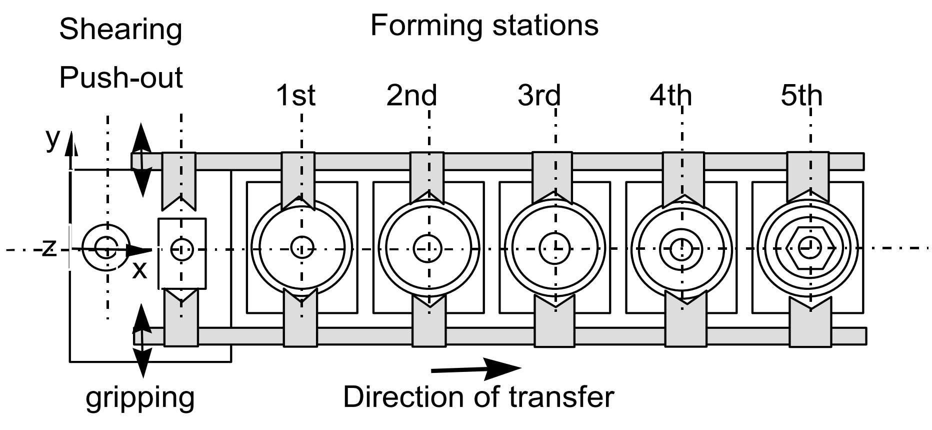

Fig. 1 Scheme of the automatic transfer system

Process planning for such machines, including forging operation sequencing and grouping, tool sets design and machine timing together with tool manufacture and machine setting, take up a significant proportion of the total manufacturing lead time. Furthermore, process planning functions require the skills of experienced personnel.

Timing an automatic multi-stage press is an essential part of the process planning task and is basic to the proper operation of the machine. It requires complete co-ordination of the transfer system and workstation actions to be accomplished with split-second timing and accuracy. Reduction of the lead time to manufacture, as well as effective deskilling of critical tasks, are typical benefits expected from the implementation of computer aided procedures in the production preparation departments. Recent contributions to the development of computer aided design systems for cold forging processes, as well as for the related process of hot forging. Confirm the effectiveness of computerised techniques in facilitating and rationalising process planning for forming processes [1-7]. Completing such systems to include computerised procedures for the machine timing function is a logical development with expected benefits in reduced lead times.
The purpose of the study described in this paper has been to design and develop a 3D computer aided Procedure module integrated into a CAD/CAE environment for the complete timing of automatic multi-stage forging machines, which would be a part of an integrated forging process planning system. In addition to timing the transfer system and station actions the module's capabilities include:

- (i) the interactive simulation and animation of movements of the machine with relevant punch, die, ejectors and transfer grippers,
- (ii) automatic proving of the timing plan against collisions,
- (iii) modification of the press setting parameters and modification of the tool sets components dimensions which can be updated automatically into all the relevant parts. Thus permitting a complete error-free timing table to be obtained as a final printout.

2. The machine timing problem analysis

The set of workstations installed on typical automatic transfer forging machines usually includes a number of forging stations ranging in general from 2 to 6, depending on the size and power of the machine. Some of them will also include a shearing station, a push-out station and others will use directly the cut billet.
Figure 2 shows a schematic view of the workstation acting on a five-forming-station machine,

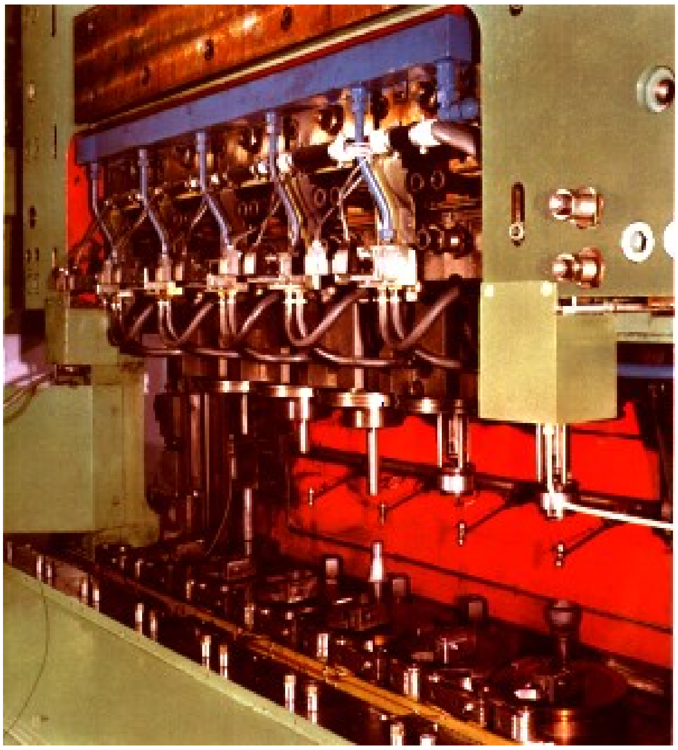

Fig. 2 A view of the workstation acting on a five-forming-station vertical machine

The production process begins with shearing of the wire and ends as the finished slug drops out of the last forming station, The shearing and various forging operations are performed during one crankshaft revolution, so that one finished part drops out of the machine at each pressram stroke. The transfer mechanism must not only move the slugs from the station from which they have been ejected to the subsequent one, but must also locate and hold the slugs in the correct position until the punches impact and push that into the die-cavities. Transfer system for these progressive machines is always synchronous, with a gripper unit for each pair of adjacent workstations. The actions of the gripper fingers and the transfer motion as shown in the travel/time diagram of Figure 3 are simultaneous.
Timing the machine consists essentially in assigning stroke lengths and stroke positions to the transfer system and workstation actions in order to coordinate their sequence. The actions to be timed are ejection of the cut-off the push-out station (figure 1), the die-side and punch-side ejection of slugs, their gripping and transfer. The stroke length and position for each are controlled by steplessly and individually adjustable cams.

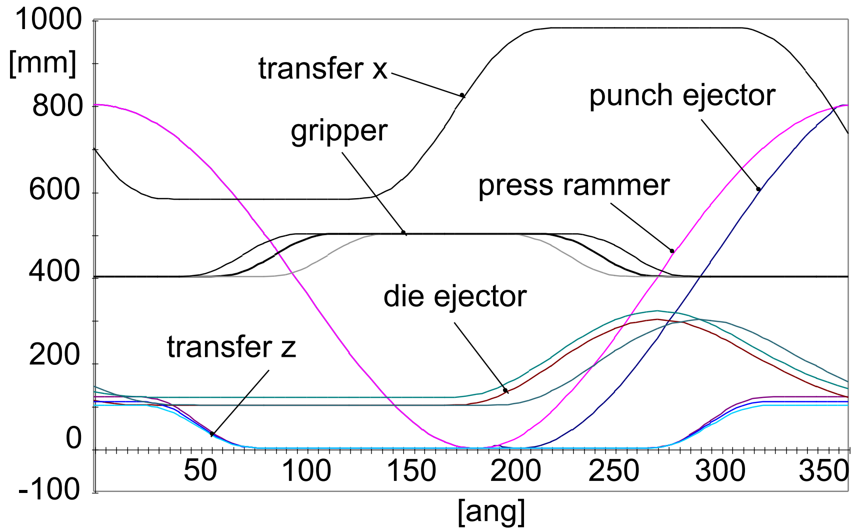

Fig. 3 Travel time diagram of the multi station press

The timing procedure is, therefore, part of planning the forging process, contributing to the check of the forging sequence design for producibility on the candidate machine. Sometimes a correct timing can not be achieved and partial redesign of tools or complete revision of the preform sequence can be required.

(i) Billet preparation

The billet preparation is the first operation of the forging. This is carried out at the shearing station and the push-out station adjacent to (Figure 1). It consists of pushing the cut billet out of the bore of the moving shear blade into the two fingers of the first gripping unit. The back-and-forth motion of the push-out pin through the blade bore has to be timed in such a way that the billet is ejected and the pin retracts while the shear blade is stationary in front of the push-out station. This situation is used for the wirebar materials for cold forging. In the warm forging the billets are cut separately then transmitted to the heating line. They are heated and transferred into the push-out station and are positioned for gripping.

(ii) Die-side Ejection

The ejection operation is carried out at every forming station of the press and has the task of pushing the slug out of the die after forming and inserting it into the grippers for transfer. The length of the ejection stroke depends both on the shape of the slug (depth of penetration into the die, recesses on the die-side, etc.) and on the forming operations. Some operations such as heading and backward extrusion, need the slug to be supported by the ejector rod, whilst others need a clearance of a few millimetres between the slug and the ejector. In timing die-side ejection, co-ordination with punch-side ejection, gripper closing and transfer has to be accomplished in order to avoid improperly gripped slugs or collision between fingers and slugs.

(iii) Punch-side Ejection

This operation is used only at the stations where slugs are formed on the punch side. It prevents sticking of the slug on or into the punch, otherwise slugs would be pulled out of the die too early during the pressram return and could not be correctly picked up by the grippers. The length of the ejection stroke depends on the penetration of the slug into the punch. The stroke is positioned within the pressram return by first setting an idle stroke. Like die-side ejection, proper timing of punch-side ejection requires co-ordination with gripper closing and transfer actions.
Since that sometimes the die-side and punch-side ejectors will operate together for holding the slug, the synchronous motion of both sides should be controlled in order to avoid the collisions between the slug and ejectors. If the movement of the die-side is faster than punch-side the collision will be happened between the slug and the punch-side ejector.

(iv) Gripping and Transfer Operations

The mechanical transfer-press can be distinguished into horizontal and vertical machines and equipped with different types of devices for handling the partially completed parts among the different stations. The most usually used grippers can be simplified into two types as shown in Fig. 4 which present the main block dimensions of the gripper and the profiles of the slug which will be kept. They are created in 3D model. The positioning in the machine can be described by co-ordinate systems.

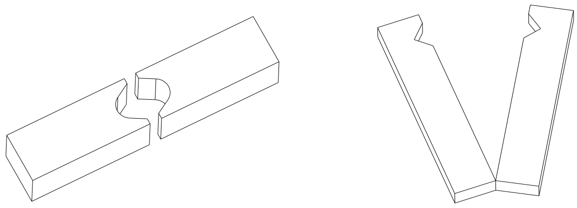

Fig. 2 The 3D models of the grippers

Opening and closing of the fingers which pick up the slugs during transfer are controlled by individually adjustable cams for each gripper unit, whilst the transfer motion is driven by an independent transfer cam. Gripper opening has to be timed in such a way that opening starts as soon as the slug is held between die and punch. In timing gripper closing, care has to be taken that the slug is already held by the two gripper fingers while still being guided by the die during ejection. Typical problems consequent on improperly-timed gripper opening or closing are gripping or canting of the slug when pushed into the die, as well as fingers colliding against the slug or the punch.

While the slugs are picked by the grippers the transfer system will transmit them from the preceding station to next one. According to the press the transfer may arise first the slugs then moves along with the longitudinal direction. It is also important to exam the collisions between the slugs, grippers and dies or punches.

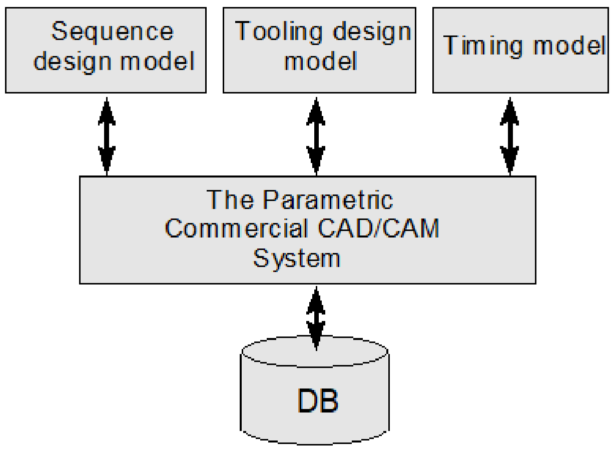

Fig. 5 The interactions among DB, commercial CAD/CAM System and the developed models

3. Current practice in machine timing and its limitations

Currently, nearly all the activities involved in machine timing are performed at the site of the machine by machine operators. Coordination of the various actions is accomplished at the end of an iterative procedure consisting of running the pressram to specific positions and then repeating adjustments and checks until correct stroke lengths and times are achieved. Usually dummy slugs are used for this task and collisions arising between punches, gripper fingers and slugs during production trials often compel complete revision of the timing.
The documents an operator needs to time a machine are the travel/time diagram of the specific machine, a drawing of the tool set assembly for the workpart to be processed and, sometimes, additional drawings representing the paths of standard fingers of the gripper units. A simplified travel/time diagram is shown in Figure 2: it summaries travel/time characteristics and adjustment ranges for each machine motion involved in timing.
In current practice, timing is a trial-and-error procedure and needs experience gained through long practice on the machine. Most of the time-consuming activities are carried out at the machine site, thus increasing the non-operational contribution to the manufacturing leading-time. The same problem happens also for the tool set designers while designing the tool system. All the press timing parameters have to considered for decide the ejector dimensions, slugs' positions and grippers shapes. It is true that sometimes some errors of the tool set design will make the machine setting up impossible. In this case, first the tool set have to be redesigned then the timing operation will begin from the initial step.

4. Integrated approach

Although the application of computer aided design techniques in forging process design has shown progress in recent years, it is still limited to the use of commercially available CAD/CAM system to model the part and die geometries and to prepare NC codes for die sinking purpose, and the use of analysis tools to evaluate and validate forging designs. Similar to other mechanical design tasks, the forging process design is very complex and knowledge intensive. A lot of research has been done for developing the KBS based system for forging sequence design, systematic based tooling design.
Most of these systems are based on the 2D graphic model and some 3D tool-set design system have been applied in forging industries.
In this paper a 3D timing module based on the press movement curve diagram will be presented to show the efficiency of using the commercial CAD/CAM system. A parametric CAD/CAM system is selected for the developing environment due to the possibility of exchanging of the information among the various models.
Figure 6 shows the architecture of integrated parametric CAD/CAE model for forging process design.

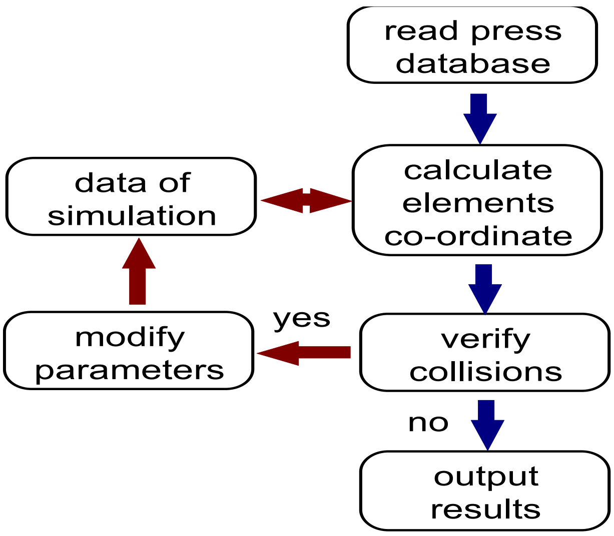

Fig. 6 The simulation engine

The base environment is a commercial parametric CAD/CAE system in which most of the modelizations of part geometries, assembly operations, NC code generations etc. can be operated as normal CAD/CAM system. Some design parameters can be created updated and transferred among the various models thanks the functionality of the parametric system. Based on this environment the forging sequence model, forging tool set design model and forging press timing model can be developed for forging process planning.
The sequence model will assist the process planner to design the forming slug sequences by measuring the volume or partial volumes of the slugs, by calculating the forming rates for each forming operation. Some KBS based sequence management system can be integrated into the model in order to manipulate the experienced sequences database by utilising the variant approach which will accelerate the design procedures. The designed sequence slugs geometry in 3D model can be used directly for the tooling design and the timing simulation.
The tooling design model is another added model which aimed to assisting the forging tool set design. The experienced tool assemblies and tool components can be created and manipulated by CAD system depending on the classifications of the forming operation function of the tool structures. The model will assist the designers to search and retrieve the proper assemblies according to the slug shape, forming operations on die- and punch- side and the press utilised then assemble them together with the slug. Deciding the parting line of the tool system the geometries of die and punch will be created very easily assisted by the model based on the slug geometry. Some standard tool components will need to be modified for fitting the slug’s dimensions. Verifying the assembly relations and tolerances the dies and punches manufacturing NC code can be created.
The timing model is aimed to simulate the press movements with the tooling and transfer system as a virtual working cell. The tool punch- and die-side envelops, ejectors envelops should created first by using the tooling created in tooling design model. The grippers can be created or retrieved from the CAD system. The timing model will assemble them with the slugs for timing simulation and animation. The 3D timing model presents the advantage that it is possible to not only be used for the axisymmetric forging components but also to be used for non axisymmetric components. The real space geometry of the parts can be checked for the collision examination. With the parametric CAD system it is also easier to modify the components dimension of the tooling and the transfer system, the results will be updated automatically.
Assisted by the timing model the press movement regulation parameters can be changed according to the forging timing simulation. In this way the machine setting up can be simulated and animated on the computer screen. Confirming that there is non collisions and the transfer action is correct the press setting parameters can be printed out for workshop use. This paper will present the detail of the timing model.

5. Timing module architecture

The module is developed directly inside a parametric commercial CAD/CAE system. By using the build-in developing toolkit of the system the model architecture is structured as shown in figure 6.

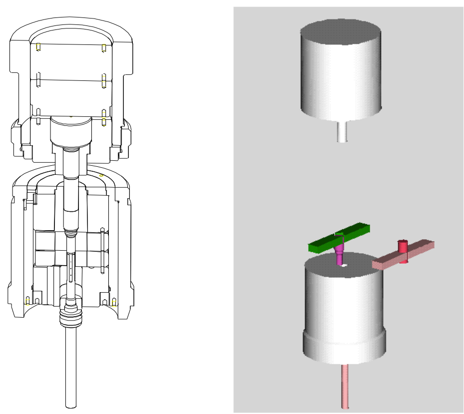

Fig. 7 The toolkit to develop the elements to be used by the timing module

The program is written in program language C.
A set of menus have been created for assisting the user in the design tasks. A central CAD database have been created to store the standardised tool components, special dies and punches as

well as the assemblies. The procedures can be described with three sections: i) tooling envelops creation; ii) timing module setting up; iii) timing simulation.

1) ***The creation of the envelops***

In order to make the simulation and animation faster the envelops of punch, die and ejectors are used in the timing simulation module. After all the tooling design task finished, the envelops of die-, punch- and ejector-assemblies can be created by utilising the profiles or directly coping the special punch or die components' geometry (Fig. 8). It is also important to set up the essential relation parameters that will be passed from the modules. These parameters include:

- the co-ordinates of the die, punch, ejectors;
- the length of the envelops;

Some relations are also necessary, for example:

Punch envelop length = Length of the punch sub-assembly
Die envelop length = Length of the Die sub-assembly
Die-side ejector envelop length = Length of the Die-side ejector assembly
...

All of the parameters and relations are transmitted between tooling design and timing simulation modules. It makes the possible that the real dimensions of the tooling will update automatically into the simulation module after the tool set is modified.

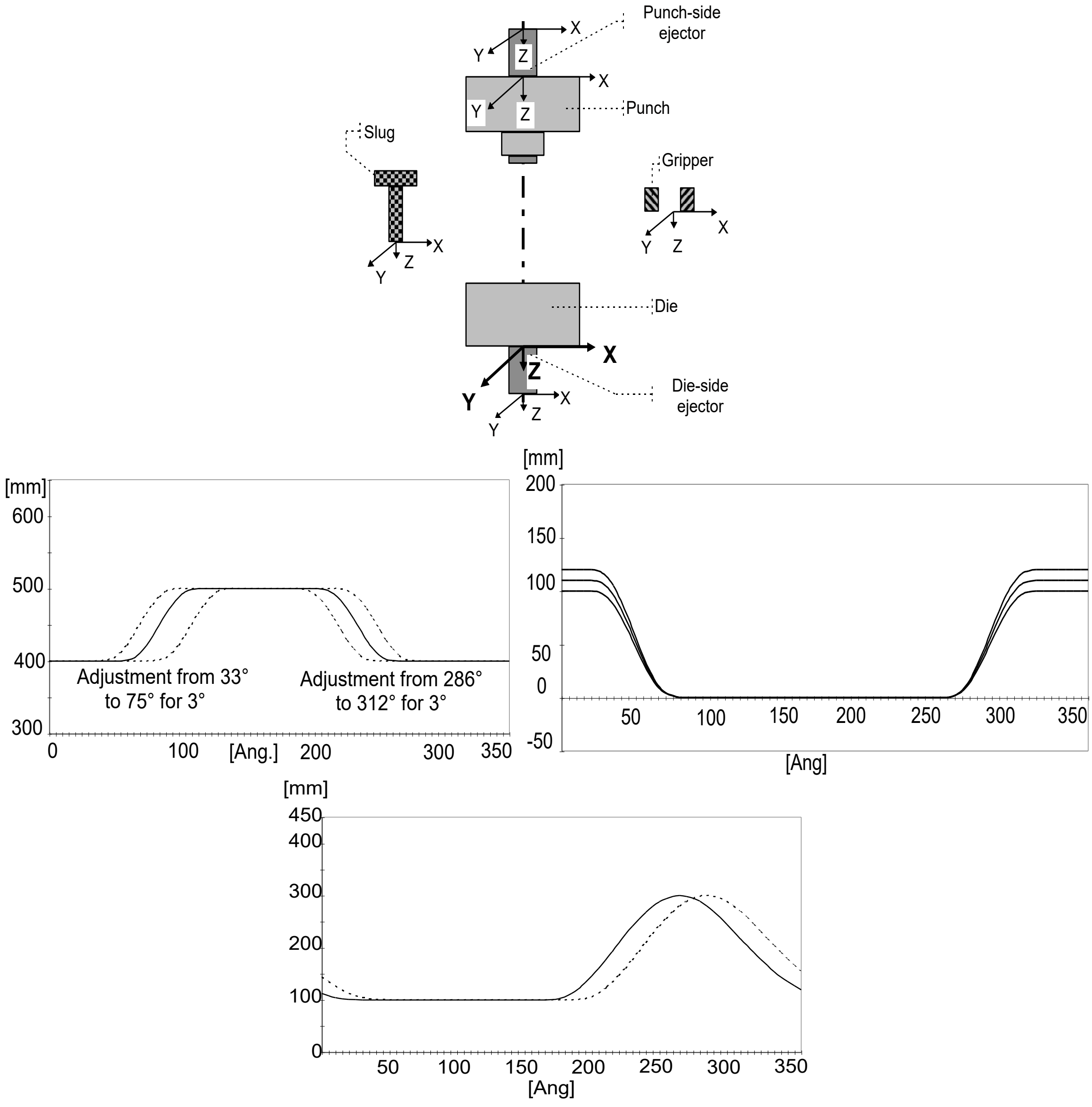

Fig. 3 Punch-, die-ejector, slag, gripper reference and relevant travel-time diagram

2) *Timing module setting up*

The timing module is an assembly 3D CAD module in which all the relevant coordinate system are constructed for every part of the simulation elements as shown in figure 6. All the created envelops, slugs and grippers are assembled respect to the proper coordinate systems. The movements of each component are calculated based on the die coordinate system.

The module is designed for only one station simulation. The multi-stage press is simulated station by station. In order to make the simulation continuous, a single module consists of one set of tool set, two slugs (precedent slug and current slug) and two gripper sets (current gripper and successive gripper). In this way the data can be transmitted from the precedent to next.

3) *Timing simulation*

Because the CAD 3D component and assembly modules are used so the real space simulation can be processed in the computer. The module consists of three main parts. The first is standardised gripper database, the second is press database in which stores all of the machine animation information and the third is the programmer for calculating the movements and collisions according to the press motion rules. The setting conditions are determined for each station of the machine in turn.

3a)The Standardised gripper database

The mechanical transfer-press can be distinguished into horizontal and vertical machines and equipped with different types of devices for handling the partially completed parts among the different stations. The most usually used grippers can be simplified into two types as shown in fig. 5 which present the main block dimensions of the gripper and the profiles of the slug which will be kept. They are created by parametric CAD system in 3-D model. The positioning in the machine can be described by co-ordinate systems.

3b)The curve diagram and press database

The category of the cures can be classified to two kinds: the fixed curve, for example, the pressram curve (Fig. 3); adjustable curve, for example, gripper closing curve, transfer curve and ejection curves.
The possibilities of the regulations of curve can be classified into 3 types:

- <u>*Transferable type curve*</u>
  This kind of curve has a characteristic that all the curve shape will be transferred forward or backward for some degrees respected to the original pressram rotation (fig. XXX). They are usually applied for the ejector's adjustment.
- <u>*Range independent transferable type curve*</u>
  This type of curve can be regulated by the range of the curve. In every range the curve is transferred as previous, but each curve can have more than two ranges. This category of curve usually appears for the gripper closing and opening movements regulation in order to adapt the picked up slug dimensions.
- <u>*Family type curve*</u>
  A family of curve has more than two independent curves. They can have totally deferent shapes but they are respected for one part movement. One time only one curve is employed for the movement rule. The regulation of the movement is realised by change the collection from the part to the curve. The typical application for this kind of curve is for transfer Z axis motion adjustment.

The press database is derived from the travel-time diagrams of the machine (Fig. 3), which are usually furnished together with the machine and currently used by sequence designer and machine operator to perform the timing. They are stored in digital format referencing the main crack shaft angle of the press. The curves are translated by cubic B-spline type curve fitting algorithm.
All of the curve characteristics are also saved in the database (e.g. which type of adjustable curve it is and what are the limitations of the max. and min. adjustable values, etc.). Reading the database the programmer can know which curve can be adjusted and in what rule to calculate.

3c)*Module for simulation*

The module handles all activities for simulating the press setting up on computer. The steps to do it can be summarized as follow:

- retrieving the envelops into module and assembling them with the two slugs and the two grippers (precedent and current at this station).
- reading the press database and the parameters for positioning the punch-, the die-, the ejectors-envelops, slugs and grippers according to the mechanism of the press. Some parameters and relations are passed from the tool set design section.
- configuring the press mechanism curves for current simulation according to the product dimension.
- starting the simulation.

The flow chart of the simulation engine is shown in Fig. 8. It controls the collision among the punch, the die, the punch- and die-ejectors, the slugs and the grippers continuously. The programmer can make evidence sign while the interference is found. All the simulation data can be checked during the work.

If the setting up is not satisfied the user can change the mechanism curve of the press very easily by menus. All positions of the parts can also be modified easily to take the adjustment of the press parameters.

If it is necessary to modify the tool sets, the designer can activate parallel the tool design module to make all modification possible. The changes will automatically be updated into timing module thanks the parametric CAD/CAE system and the current parameters will be kept controlling the interference in the new simulation circle.

The final results include:

- detailed design.
- all tool documentation including the drawings of assemblies and parts ; bills of materials.
- press setting up parameters.

6 Example

Figure 9 presents different steps of the timing simulation using

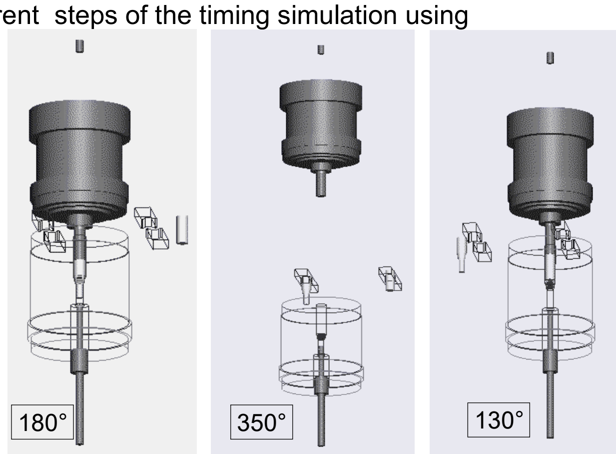

Fig. 9 Examples of timing simulation

7 Conclusion

The virtual set up of multi station presses allows:

- easy generation and test of alternative sets of adjustment parameters,
- reduction of modifications of the tooling system, and
- considerable reduction of the time for setting up and timing of the press and of the total lead time to manufacture.