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Collaborative Research Work in Cold and Warm Forging at University of Padua, Teksid and Carraro within the Eureka "E.F.For.T" Project

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Abstract

The ongoing collaborative research work at the University of Padua and the two companies Teksid and Carraro within the Eureka-Famos "E.F.For.T" project is presented. The project is aimed at developing and introducing cost-effective forging methods for precise and net- or near-net-shape forged products through the realisation at the companies of novel forging environments where pilot-plant facilities for forging (including cold, warm and hot forging) and tooling preparation are integrated with advanced software and simulation tools for product design, process planning as well as product quality management and assurance.

In the presentation particular emphasis will be put on the collaborative effort between industry and university as well as on progress in developing (i) the integrated CAD/CAE system for process design and (ii) physical and numerical simulation of cold and warm forging operations.

1. INTRODUCTION

Today forging technology offers a great potential for new forging methods and types of product, mainly in the area of precise and net- or near-net-shape forging.

The demand for more precise forgings of intricate shape comes mostly from automotive industry (e.g. constant velocity joint components, variable gear racks, splined gear wheels, etc.).

To meet this demand, current R&D activity in the field of forging is aimed at developing and introducing in the forging industry new steels and Aluminum alloys, new forming methods (such as combination of cold, warm and hot forging) and new forging systems based on innovative forging equipment, advanced die-making technology as well as simulation and computerized techniques for product and process design.

At the same time, forging industry is urged to move from high production-volumes to medium- and small-quantity production in order to meet diversified needs of the market. Both new machines fitted with automatic tool changing and tool setting systems and CAD/CAE tools for process simulation and design seem to be effective, for different reasons, in increasing volume flexibility in forging.

The paper presents the ongoing collaborative research work at the University of Padua and the two companies Teksid and Carraro within the Eureka-Famos "E.F.For.T" project. In the presentation particular emphasis will be put on the collaborative effort between industry and university as well as on progress in developing (i) an integrated CAD/CAE system for cold forging process design and (ii) physical and numerical simulation of cold and warm forging operations.

2. THE EUREKA-FAMOS "E.F.FOR.T" PROJECT

In the EUREKA-FAMOS's project portfolio as at summer 1994, "E.F.For.T." (acronym of Integrated Environment For Precise and Net-Shape Forging Technology) is the only project dealing directly with forging and forging-related technology. A profile of the project is summarised in Fig.1.

The objective of this project is to develop and introduce cost-effective forging methods for precise and net- or near-net-shape forged products through the realisation at the companies playing in the project the role of end users of novel forging environments where pilot-plant facilities for forging (including hot, semi-hot and cold forging) and tooling preparation are integrated with advanced software and simulation tools for product design, process planning and preparation as well as product quality management and assurance. The set of technologies involved in the development and exploitation of such a novel environment pertain to the three areas of:

(i) product design and engineering,
(ii) production preparation and
(iii) production of forgings.

The project team consists of (i) three companies, each of them playing the role of end-users of separated pilot plants, (ii) two research centres with the role of know-how and technology supplier and one University department participating in the R&D activities, managing the project and co-ordinating the contributions from the different partners.

As regards the first area, the project is concerned with developing a comprehensive and integrated software environment for design and engineering of precise and net-shape forgings. The software system will cover all the concurrent engineering activities leading to a complete design and planning of the process, including

- designing preforming sequences,
- evaluating tool stresses and wear distribution through an accurate simulation of the metal flow into the die cavities,
- designing the set of tools,
- preparing NC-data for NC machining of tools,
- designing the handling devices and determining appropriate machine setting conditions, and
- preparing an offer for a new product and an analytical estimating of production costs, including tooling and machine operating costs.

Particular emphasis is put on the design of tools on the basis of the accurate knowledge of loads and temperatures in the forging process. To this regard extremely important are the development and application of techniques integrating numerical and physical simulation of the process.

Technologies pertaining to the area of production preparation are mainly concerned with manufacture of the tooling system, including advanced methods for milling and finishing cavities, surface treatments and coatings.
To the area of forging production pertain the techniques related to process development and monitoring, besides the activities leading the pilot plants to be working.

Remarkable is the multi-disciplinary aspect of the efforts involved in carrying out the project, which encompass expertise in different disciplines such as manufacturing, materials, physical modelling, software development and computer applications including CAD/CAM, A.I. and databases.

Main technological objectives of the project are:

- extending process capabilities to include new types of product,
- improvement of the intrinsic product quality,
- improvement of planning and production efficiency and
- increasing competition of the forging technology in the area of Small Quantity Production (SQP).

3. THE CAD/CAE SYSTEM FOR COLD FORGING PROCESS DESIGN

The concurrent engineering activities leading to a complete design and planning of the cold forging process for a typical part include tasks such as

- determination of a suitable processing sequence,
- selection of the appropriate manufacturing equipment,
- technological evaluation of the forming sequence e.g. in terms of distribution of strain in the forged component and load peaks in the different forming stages,
- design and manufacture of the tooling system,
- design of the machine set-up, including timing of the machine motions for automatic multi-station machines, and
- estimation of the manufacturing costs.

As shown in the scheme of Fig.2, the CAD/CAE system consists of modules covering all the above tasks [1]. They provide the user with a suite of computer- and A.I.-based tools for the design of the whole forging process.
The development of modules of the system started under the BRITE project P-2018. The completion of the modules, their validation in an industrial environment as well as the extension of the system capabilities to new class of components are tasks of the ongoing EUREKA project.

<u>Computer-Aided sequence Design</u>

The module for computer-aided sequence planning (Fig.3) assists expert designers in (i) generating forming sequences for solid and hollow rotational parts and (ii) testing them for suitability. The program architecture has been planned in close co-operation with designers of different companies. It should be thought to as a sort of CAD system tailored for sequence planning, assisting expert designers with a set of tools increasing efficiency in sequence generation and testing [2].
A prototype for automatic sequence planning is also part of the program, to be fully developed for specific part families after conclusion of actual tests.
To make easier installation at the different industrial sites, the program runs under different Operative Systems either as a stand-alone software or utilising nearly any CAD system user interface.

Tool-Set Design

At the time of writing, the development of the module for design of tooling systems in cold forging is still in progress. The module architecture (Fig.4) has been designed in close co-operation with designers of Teksid, which is the largest Italian manufacturer of cold forged parts. It has been conceived as an application of a CAD system, taking advantages of CAD DB and of parametrical design capabilities of the latest generation of CAD systems.

Timing of Multi-Station Presses

The module for timing of presses guides the user in the timing and setting up of automatic transfer presses, both vertical and horizontal, for cold-, warm- and hot-forging [3]. The module allows a complete off-line timing and setting up of the machine (keeping it working) as well as a verification of the forging sequence for producibility, before tooling system is manufactured.
Module capabilities include (i) timing of transfer system and station actions, (ii) interactive design of non-standard gripping devices and (iii) automatic collision check (Fig.5). As final result of the working session a complete error-free timing table of the press is obtained and stored in a printable file.
The structure of the module allows portability on a number of CAD-platforms requiring on principle the availability of solid- or surface-models of objects.

Offer Preparation and Evaluation

The module for offer preparation consists of a set of software procedures aimed at estimating production costs for cold forged parts at the very early stages of process design. These procedures are intended to be used as a supporting tool for decision making during the offer preparation. at these stages, the product design has been already decided in its most important features and information regarding the production volume is available, but neither the process nor the tooling system have been defined in detail [4, 5].
Statistical methods are applied to production cost data of parts previously forged. Accordingly, the procedures refer to the technology, experience and performance standards of the specific company.
The program has been developed in Excel 4.0 environment. A number of basic inputs are required. Some of these (such as production size, part weight, labour cost) are directly introduced in the algorithms. others can be considered access keys for data bases: as the user selects the equipment and the part family, data stored in the corresponding data base transferred to a temporary sheet, where calculation are executed.
An example of the program output is given in Fig. 6. The user can easily evaluate what happens if different parameters are modified: economical consequences from a set up time reduction or a batch size increase are automatically calculated.

4. THE SIMULATION SYSTEM FOR FORGING PROCESS ANALYSIS AND DESIGN

The System (Fig. 7) collects complementary techniques today available for simulation of forging operations, including:

- Finite Element simulation,
- physical simulation of thermal-mechanical operations, and
- physical modelling techniques.

Finite Element simulation is based on commercially available programs, both general purpose and devoted to forming operation analysis. It provides the process designer with detailed information on metal flow and process variables such as strain and strain rates, temperatures of dies and workpiece, deflection of tool surfaces, thermal and mechanical history of metal, textures and load-stroke relationship.

The physical simulation of thermal and mechanical operations is based on the GLEEBLE 2000 Hydrawedge, installed at the DIMEG lab and belonging to a consortium including DIMEG and three companies (Carraro SpA, Pietro Rosa TBM and Teksid SpA).
The system (some general information on GLEEBLE 2000 was presented at the last ICFG Plenary Meeting [6]) is a múlti-purpose dynamic thermal-mechanical simulator capable of multi-stage forging experiments with stroke rates up to 3 m/s. The temperature is measured and controlled by a thermocouples or a pyrometer and, during the experiments, the compression, heating and heat treatments are all carried out in situ.
For the "E.F.For.T." project purposes, the system is mainly utilised in (see Fig.8):

- generating material data and constitutive model, including true stress-true strain curves and workability data,

- replicating in test samples the thermal and mechanical profiles that locally occur in the forgings during the process and that can be predicted by FE codes and

- designing appropriate process parameters through the in situ simulation of the whole thermal-mechanical process.

Physical modelling consists in forging model-materials (waxes, aluminum and lead) components in a lab press of 2000KN (named "Toy Press") equipped with a load cell consisting of a three-plates die-set and a CA multi-component force measuring system. The X, Y and Z components of force and moment vector, in a given co-ordinate system, are measured by three force transducers based on piezoelectric sensors. Measuring ranges of the load cell vary with the preload conditions that depend on the load horizontal components to be measured. With preloads of 160 and 0 KN, measuring ranges along the vertical axis are ±40 and ±200 KN, respectively.
The two main objectives of the Toy Press are:

- measurement of the tool-loading system during the press stroke and systematic analysis of defects in cavity filling and

- optimisation of billet geometry, preforms, parting line location and flash design.

5. CONCLUSIONS

The ongoing collaborative research work at the University of Padua and the two companies Teksid and Carraro within the Eureka-Famos "E.F.For.T" project has been described.
In the presentation particular emphasis was put on progress in developing (i) the integrated CAD/CAE system for cold forging process planning and (ii) the simulation system for forging process analysis and design.

6. REFERENCES

[1] P. Bariani, G. Berti, L. D'Angelo, M. Marengo "Development of an Integrated CAD/CAE System for Cold Forging in the Automotive Industry" XXIII FISITA Congress, 1990, Torino.

[2] P.F. Bariani, G. Berti and L. D'Angelo, " A Multiple Approach Based System for Process Planning in Cold Forging: Some Recent Developments and Applications", 3rd Int Conf. on Advanced Manufacturing Systems and Technology, Proc. AMST '93, Udine 26-27 April 1993, Vol. II pp. 49-56

[3] P. Bariani, G. Berti, "Machine Timing Integrated into an Expert CAD/CAE System for Cold Forging Technology", Proc. of the 5th Int. Conf. on Metal Forming ICMF'91, Györ, 19-21 June 1991

[4] P.F.Bariani,G. Berti and L. D'Angelo, "Tool Cost Estimating at the Early Stages of Cold Forging Process Design", Annals of the CIRP , Vol. 42/1/1993, pp. 279-282.

[5] P.F. Bariani and M. Vianello, "Development of a Decision Support System for Offer Evaluation in Cold forging technology", CAPE10, Palermo, Italy, June 1994.

[6] S.T. Mandziej, "Cold Forging and Related Micro-Mechanisms of Quasi-Brittle Fracture", Proc; 26th ICFG Plenary Meeting, Osaka, Japan, September 1993.

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Project Profile

EU 668	
Acronym	E.F.For.T.
Title	Integrated Environment for Precise and Net-Shape Forging Technogy
Announced at:	Aja, 1991
Participants:	*Italy* DIMEG - University of Padua Carraro SpA Teksid SpA *Denmark* IPU *France* PSA *Slovenia* C3M
Main Contact:	Prof. Paolo F. Bariani DIMEG - University of Padua tel. +39. 49. 828.6818 fax +39. 49. 828.6816
Estimated Cost:	18,00 MECU
Time Scale:	4 years

Fig. 1 - Profile of the EUREKA-FAMOS "E.F.For.T." project.

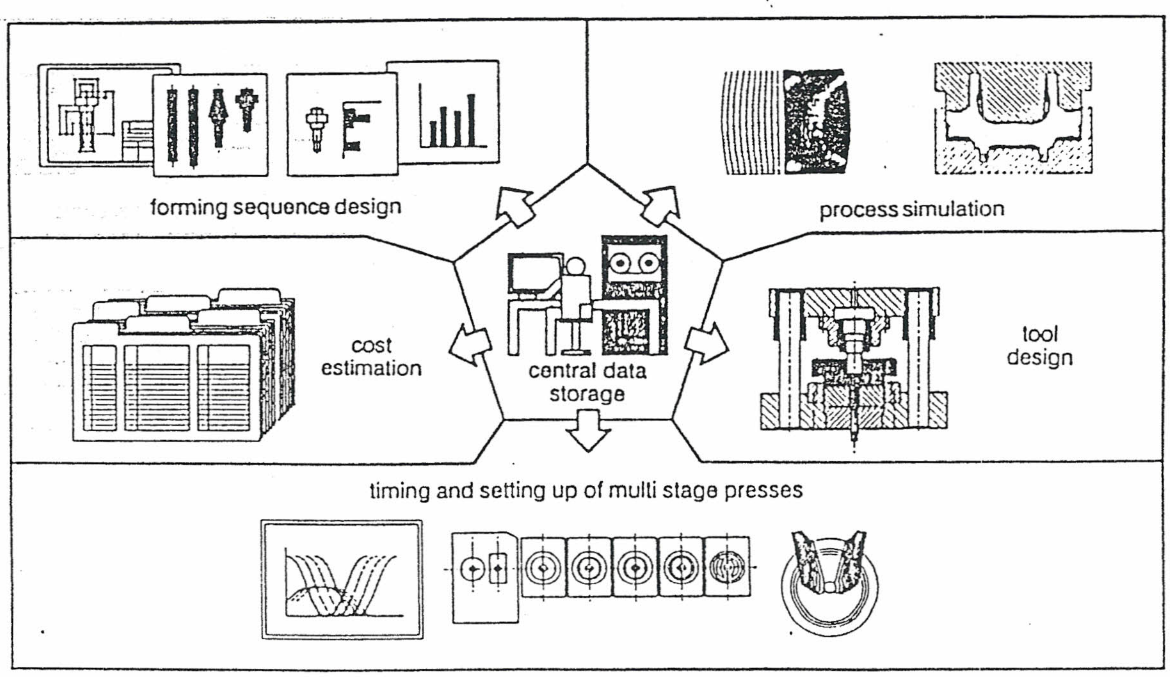


Fig. 2 - The CAD/CAE system for cold forging process design

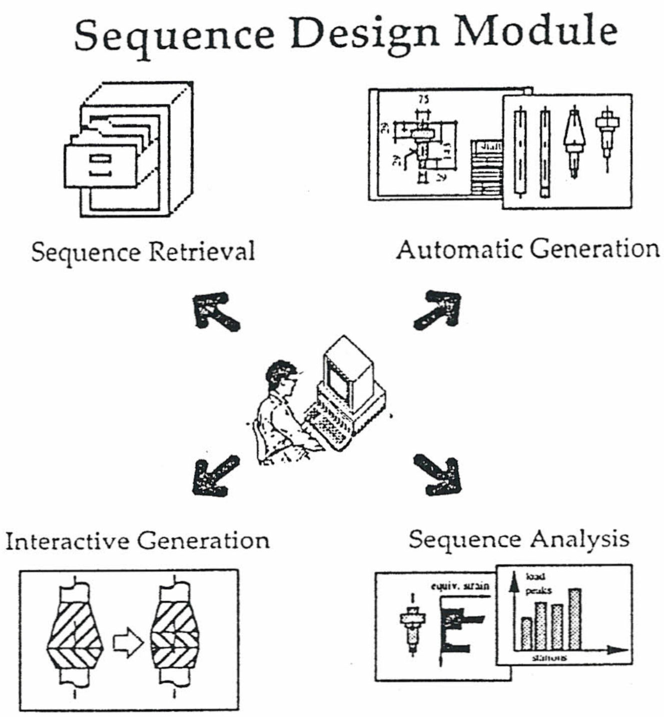


Fig. 3 - The module for computer-aided sequence planning

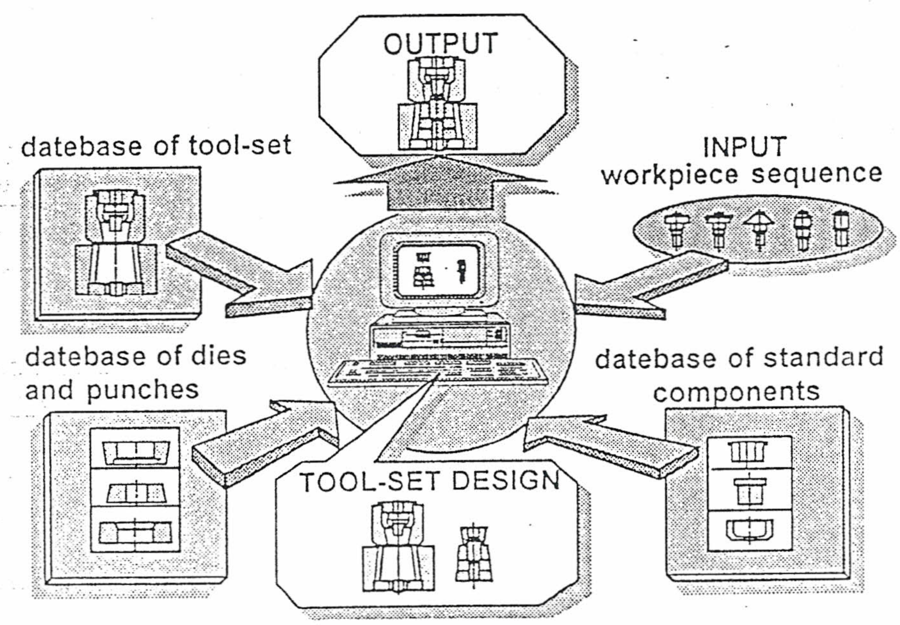


Fig. 4 - The module for design of the tooling system

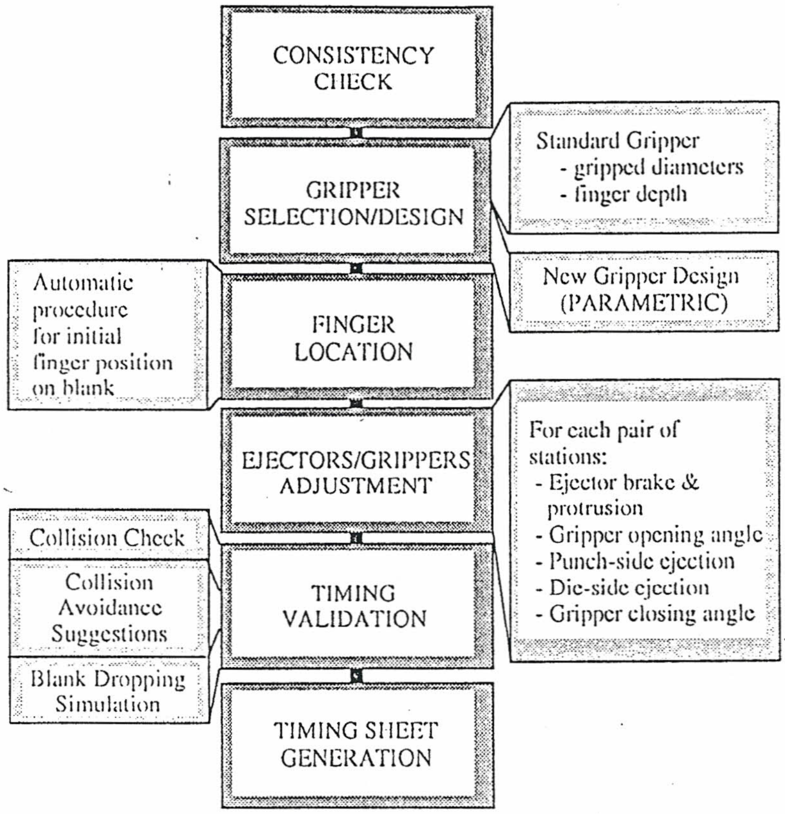


Fig. 5 - Functional architecture of the Timing Module

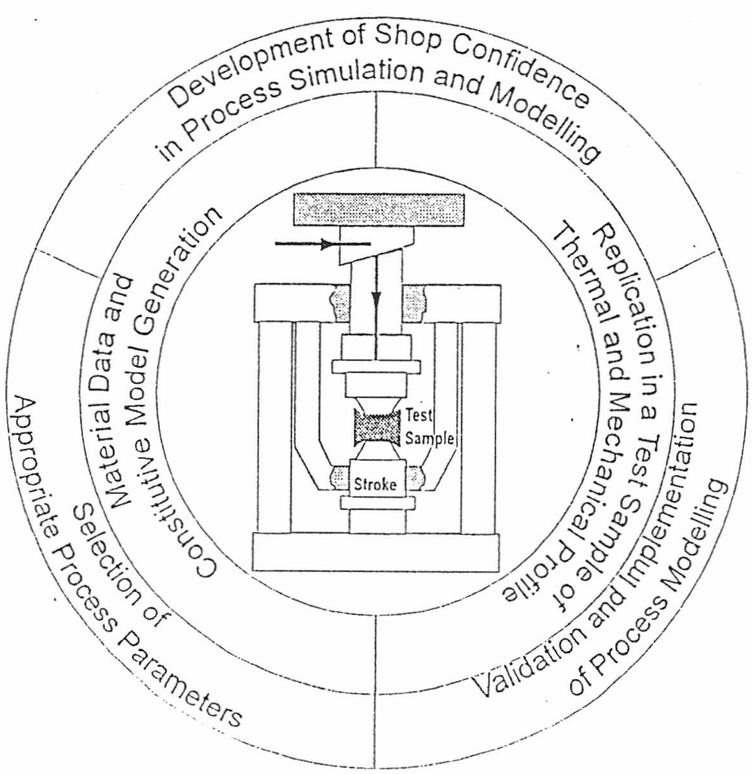


Fig. 7 - The physical simulation of thermal-mechanical operations

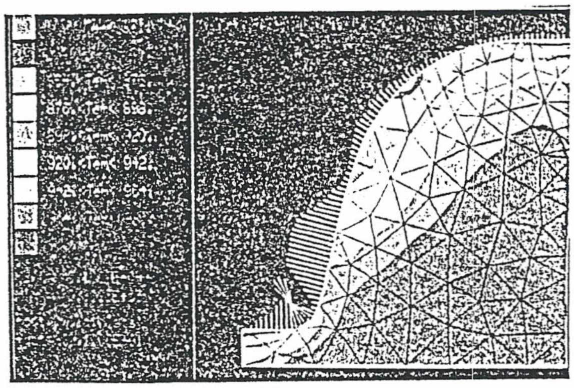
EUREKA-FAMOS "EFFORT"

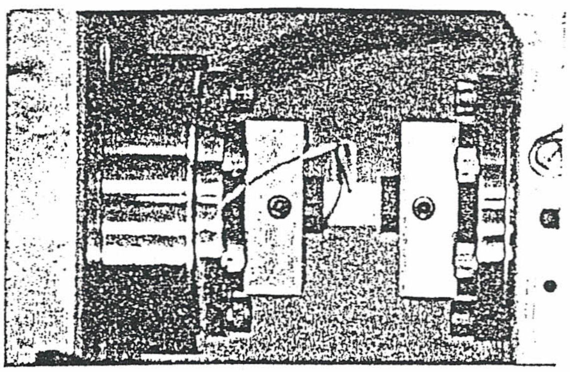
SIMULATION in METAL FORMING PROCESS DESIGN

FEM Simulation

prediction of

- metal flow
- temperature (die, workpiece)
- strain and strain rate
- stresses (die, workpiece)
- die deflection
- thermal & mechanical history
- load-stroke relationship
- texture





Thermal-Mechanical Simulation

- material data and constitutive model generation
- replication in a test sample of thermal and mechanical profiles
- selection of appropriate process parameters

Toy-Press Simulation

analysis of

- tool loading system
- cavity filling defects

optimisation of

- billet and preform sequence
- parting line and flash

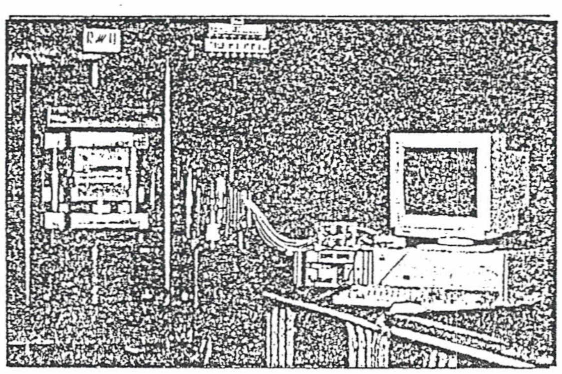


Fig. 6 - The simulation system for forging process analysis and design