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ORIGINAL ARTICLE

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Applying knowledge-based engineering to traditional manufacturing design

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Abstract The paper outlines the development of a knowledge-based engineering (KBE) system for hot forging design using state–of–the–art technology and the Internet. The benefits of a KBE approach over a traditional design process are emphasized. The aim of the proposed KBE system is to integrate the hot forging design process into a single framework for capturing knowledge and experience of design engineers. The KBE application guides the design engineer through different stages of the design process enabling the generation of forgeable geometry from a component profile taking into account machine, material and forging company specific data, and design considerations.

1 Introduction

Today's economy presents a new set of challenges for the manufacturing industry. In the UK and other developed countries the manufacturing sector is under siege because developing countries offer quality products at lower prices. Global competition has empowered customers who now constantly demand new and better quality products. To meet the challenge of foreign competition and survive in the market, manufacturers in general and the metalforming industry in particular are now under tremendous pressure to improve their efficiency in terms of product development and resource utilisation. This means a dramatic reduction in the overhead cost of redundant engineering work, eliminating repetitive design tasks, reallocating technical resources to new product development. To stay competitive in today's global economy a company must build on its intellectual capital and create time to innovate and assess more advanced, complex types of tools to eliminate uncertainty and repetition from the design process. With an ageing workforce it is vital that experience is not forgotten or allowed to drift away through retirements etc., but is captured and built upon within a company. More manufacturers are now exploring new ways to harness the advantages of new technologies and communications tools such as Internet. Knowledge-based engineering (KBE) systems, which complement traditional CAD/CAM systems by adding the engineering knowledge that drives the product design process, are becoming an essential part of strategy for improving effectiveness [1, 2].

This paper outlines the development of a KBE system for hot forging design using state–of–the–art KBE technology and the Internet. Currently most of the activities and costs related to planning forging processes depend strongly on human expertise, creativity and intuition as well as time-consuming experimental, trial and error, work. The numerous variables required to describe forging processes make the knowledge capture and the encapsulation of the decision-making and process planning rules difficult using conventional methods [3–7]. The aim of the proposed KBE system is to integrate the whole design process into a single computer model and to create a framework for efficient capturing of a company's most important asset—the knowledge and experience of its engineers. In the course of the design the KBE application guides the design engineer through different stages of the hot forging design process enabling the generation of forgeable geometry from a component profile. It also supports computation of the forging load, complexity factor, component volume, flashland ratios etc. A relational database is used to encapsulate the design rules as well as their complex interdependencies on material, production unit, and manufacturer capabilities. As part of the system a cost-estimating procedure for hot-forged parts is being developed, taking into account the size of production volume, the production unit, the production time and the dimensions of the billet and the component to determine the total forging cost.

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2 Traditional organisation of hot forging design process

As illustrated in Fig. 1 the traditional organisation of hot forging design and process planning contains several stages starting with the component design and concluding with the cost estimation and the process parameter selection and optimisation. The component design stage involves the transformation of the component geometry to obtain forgeable shape. The design tasks at this stage involve the determination of a parting line, specification of appropriate radii, fillets and corners, internal and external drafts, design of holes, ribs, and webs. The empirical design guidelines, which are used, often depend on the material, production unit and manufacture's experience. The creation of a forgeable shape is followed by the determination of the process sequence and designing all the tools needed during the production process, including those used for die profiling and trimming. The most critical and expensive tools are the forging dies, of which, for a particular forging, there may be several preform dies. The main objectives of the design of preform dies are to ensure a good distribution of material in order to fill the finishing dies without any defects, minimise metal losses and minimise die wear, i.e. minimise metal flow in the last die so as to extend its life. The perform design stage is generally considered to be the most creative, requiring the highest level of expertise. According to some estimates approximately 80% of the final product cost is decided at the design stage. Finally after all the necessary tools are created, the design engineer generates drawings and reports that document the forging design. Currently in the forging industry the design process is still mainly based on very inefficient iterative 'trial and error' procedures. After taking successive measurements of the forgings, gradual corrections to the die geometries are made, which eventually lead to the production of so called 'good parts'. Since many repetitive engineering tasks are not automated, they need to be done by hand, which creates a bottleneck that slows down the design cycle. As shown in Fig. 1 this design process is really a loop, which is repeated until a satisfactory design is found, therefore the effect of the bottleneck is multiplied by the number of times the loop is repeated.

In order to speed up the design and optimise the process sequence more often software tools such as CAD packages [8] and numerical methods like the finite element method (FEM) are used. Many studies have demonstrated that numerical analysis can help the forging industry to define the best process sequence, reducing time and costs involved [9–11]. Typically, CAD software is used to display, manipulate, and transform the component geometry, which

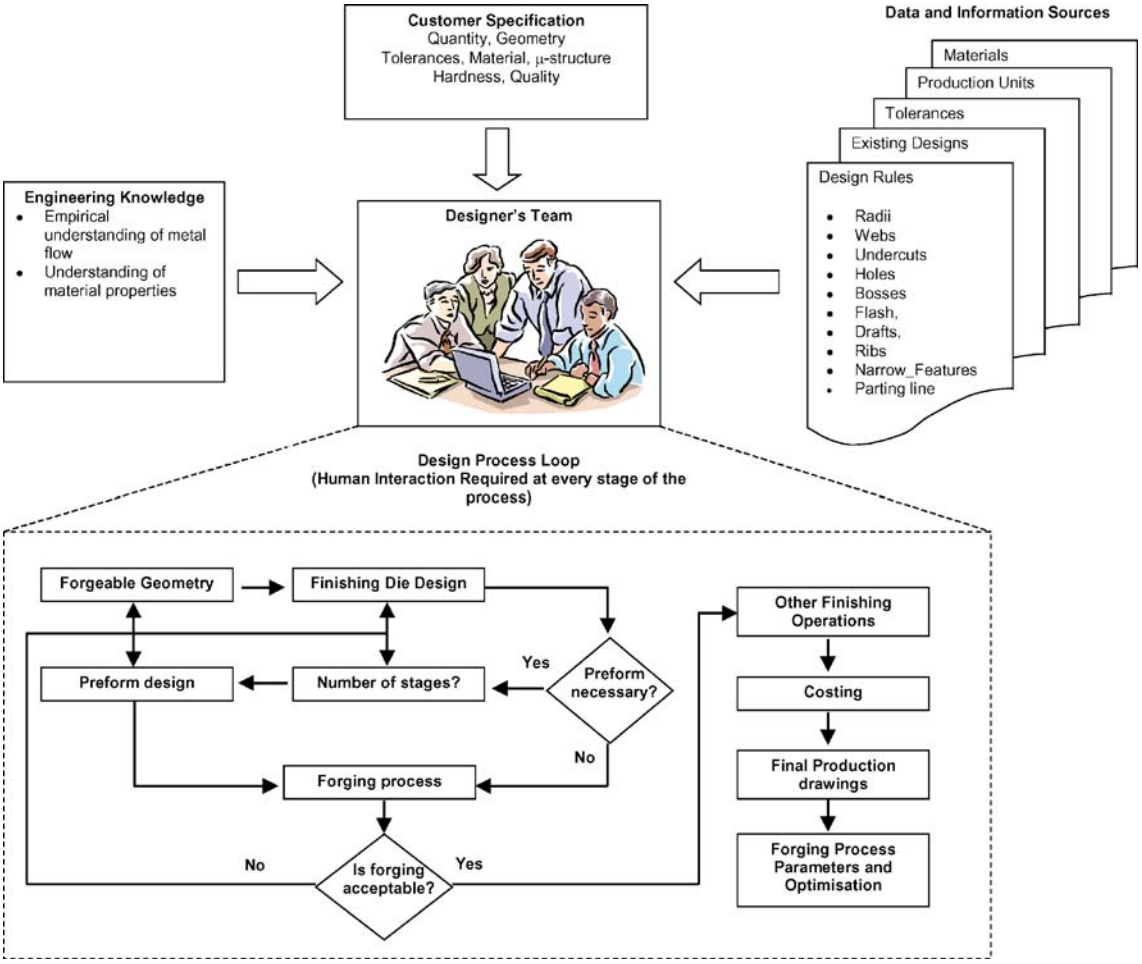


Fig. 1 A traditional, 'manual' organisation of forging design process

subsequently is exported to FEA packages to simulate the forging process. Although traditional CAD systems allow engineers to process designs faster than when designs were done completely by hand, they go only part of the way toward providing a completely flexible tool for adapting to changes in a product design and provide no means of capturing the engineering expertise behind the design. While the geometric information can be handled using CAD systems other design knowledge, including catalogues, databases, and engineering standards, must be managed separately without integrated tools. In addition, if the input specifications change at any time, the entire process must be repeated. Even with all of the engineering team's experience, the process of developing a single design is still laborious, repetitive, and subject to error. The following sections will show how this situation can be significantly improved using KBE environment.

3 KBE approach

3.1 KBE basic principles and benefits

The conventional definition of KBE is that it is "the process of combining engineering knowledge, methodologies, rules and best practices with process knowledge and best practice to create product models that describe how product designs are created or engineering analyses are undertaken" [12]. Unlike the traditional CAD systems, which mostly contain geometric information for a single design, KBE does not just create a single design; it models the whole process of generating the design. A KBE system stores knowledge about a product in a comprehensive product model composed of engineering rules that describe how products are designed, analysed and manufactured. The rules can be design rules, standard engineering rules, or experiential 'rules of thumb', which reflect years of design experience. They can be expressed in the form of physical equations, graphical and tabular relationships describing the attributes of the physical product such as geometry, functional constraints material type etc. [13]. Once engineering knowledge about the product is collected and stored as a product model, design engineers can generate and evaluate new designs quickly and easily by changing the input specifications for the product model, or modify designs by extending or changing the product model. This frees the engineer from repetitive time-intensive and often tedious design tasks such as repetitive calculations and allows more time for creative design work. Another strategic benefit of KBE is that the product model also includes various outputs such as reports of engineering results, data of engineering analysis, 3D geometric models as well as non-geometric output such as bill of materials, costs and mass estimations and manufacturing instructions [14].

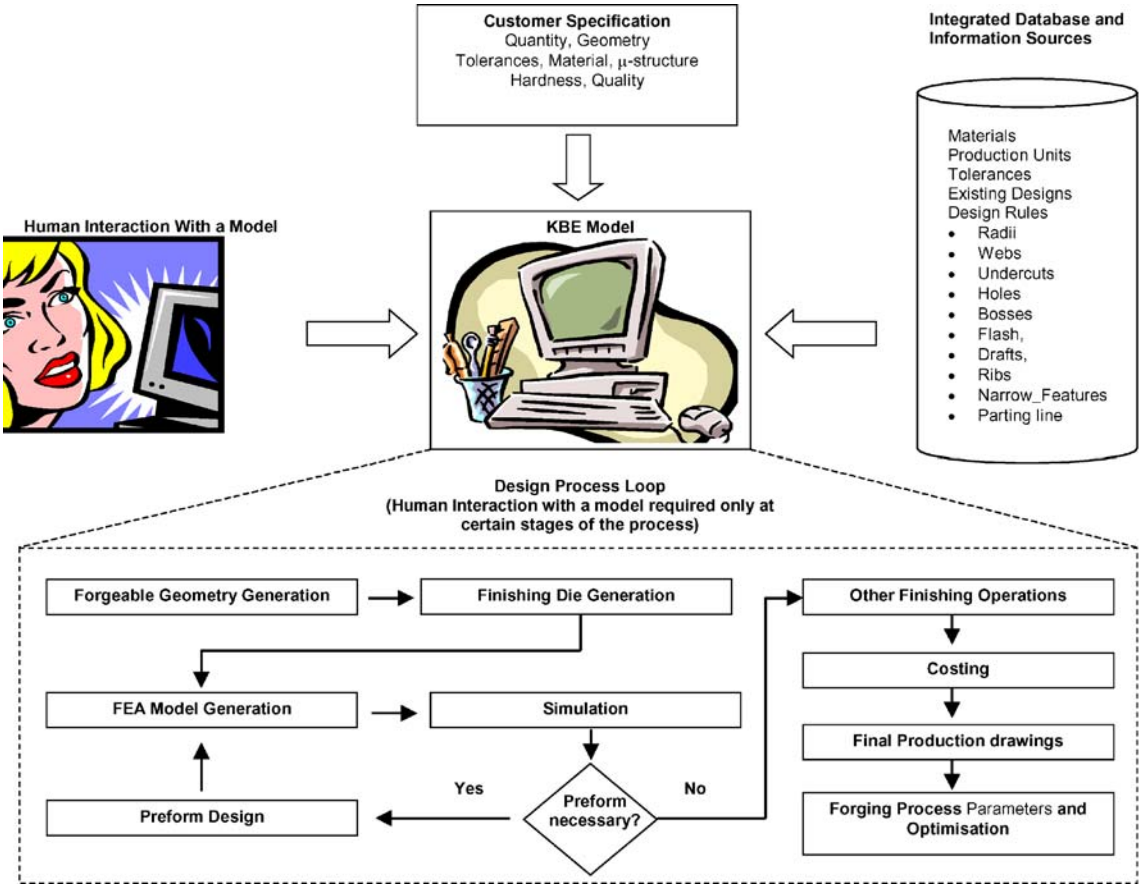


Fig. 2 KBE model of hot forging process

When the design changes, so do the outputs. Information is always up–to–date and reflects the current state of the design, automatically. A KBE system is also able to integrate other engineering programs such as FEA software in a wider organised system working as a kind of pre-processor for the analysis applications.

3.2 Proposed KBE model of hot forging

The diagram shown in Fig. 2 illustrates a proposed KBE model of the hot forging design process. The centre of the design process is the product model, which manages all the routine engineering tasks. The role of the engineer who interacts with the model is to provide the input specifications such as component geometry and make the important design decisions. Databases of materials, standards books, production units' specifications, design rules encoded in the system by the forging engineer etc., are all integrated into the product model through the relational database. First the KBE application automatically constructs forging geometry from component geometry using design specifications. Once a design has been generated from the product model, the shape can be exported to a FEA for a forging simulation allowing the forging designer to test several process parameters in order to improve the forging process. According to the simulation results, intermediate forgings (preforms) may appear to be necessary. At any stage the geometric information can be transferred back to a CAD tool for further detailing/modifications. A repository of the previous designs can be used to retrieve the relevant cases and exploit analogies and similarities with previously solved cases. The designer of preform shapes can use not only the information from the simulation results but also the solutions of a family of previously solved cases. The redesigned preform may be again validated by FEA simulation. Finally, the KBE generates automatically the document set for the forged part, e.g. the drawings, reports etc. The design engineer can easily modify the design either by changing the answers to some of the key design questions or by modifying the input specifications. In this scenario, the bottleneck of the traditional design process, the repetitive tasks that had to be done by an engineer, is eliminated. All such tasks are managed by the product model. The design loop can be repeated efficiently as many times as necessary without incurring the expensive trial–and–error procedure and experimental work. With the product model, generating a new design can be done much faster in a matter of hours by a single design engineer, as opposed to several days or weeks with traditional methods.

4 KBE technology

4.1 KBE server architecture

Traditionally, all computer aided design tools were designed as interactive applications for a single user. However, with the fast development of the Internet and database technologies, it is advantageous to build an integrated system based on the web in order to better implement knowledge share and to distribute designs [15]. The web-based environment offers several advantages in comparison to more traditional software platforms, such as: an open architecture, uniform information model, and object-oriented structure. All of these can help to eliminate the time and space restriction of engineering design and realise maximum knowledge share. The web environment also pro-

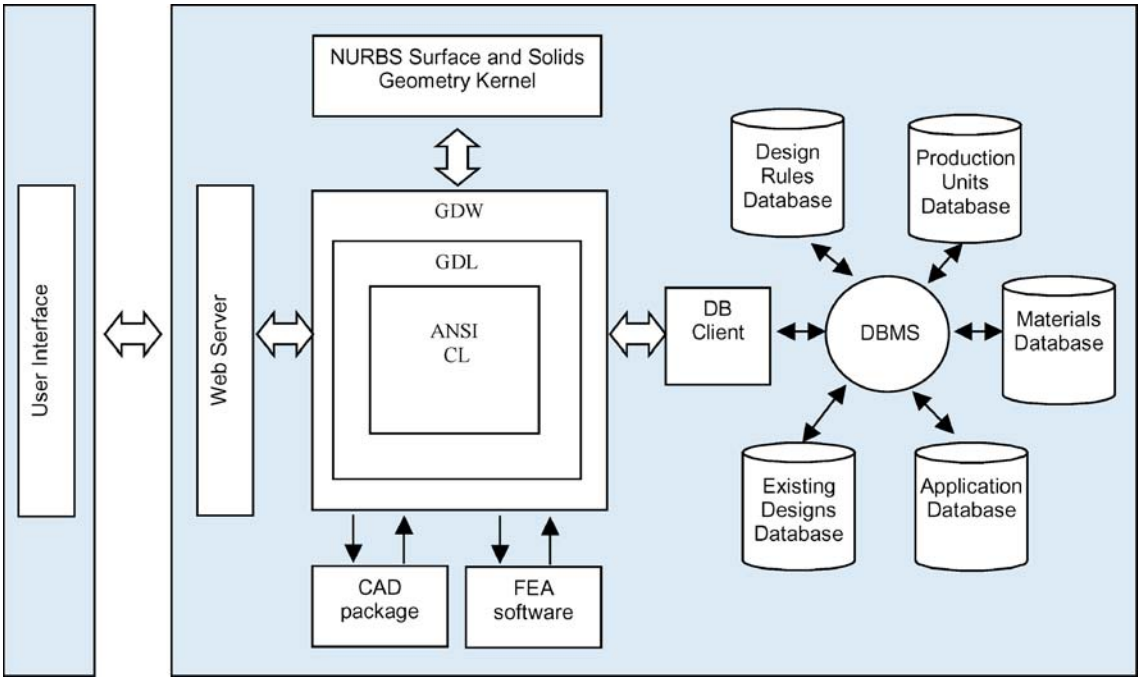


Fig. 3 KBE server architecture

vides the user interface, file transfer and can display graphics representing the geometry through any standard web browser.

The proposed web-based KBE system architecture is shown in Fig. 3. The left side of the diagram in Fig. 3 indicates user interface, the right side corresponds to the processes run and the steps carried out on the KBE 'server' machine. The core of this KBE application is the GDL/GWL (General–purpose Declarative Language/Generative Web Language) developed by Genworks International [16]. GDL/GWL is a knowledge base programming environment, which implements the features of caching and dependency tracking as well as demand–driven evaluation. Further, because GDL is based on a full object-oriented language model, a superset of ANSI Common Lisp, it follows a non-procedural paradigm for application development and execution, with multiple threads of execution and the ability to load new code and redefine objects dynamically. The server side framework is implemented using GWL as an integrated web server-based user interface that manages data and controls other software tools on the server. The main application tasks carried out on the server are: accessing the database of rules, design features and materials, facilitating file transfer between the user and CAD package or a FEA software and performing the KBE computations. GDL/GWL integrates the application logic and databases through a direct MySQL interface and handles geometry, through its library of 3D geometric objects. It is able to export and import component surfaces directly embedded in IGES format. The upcoming integration to

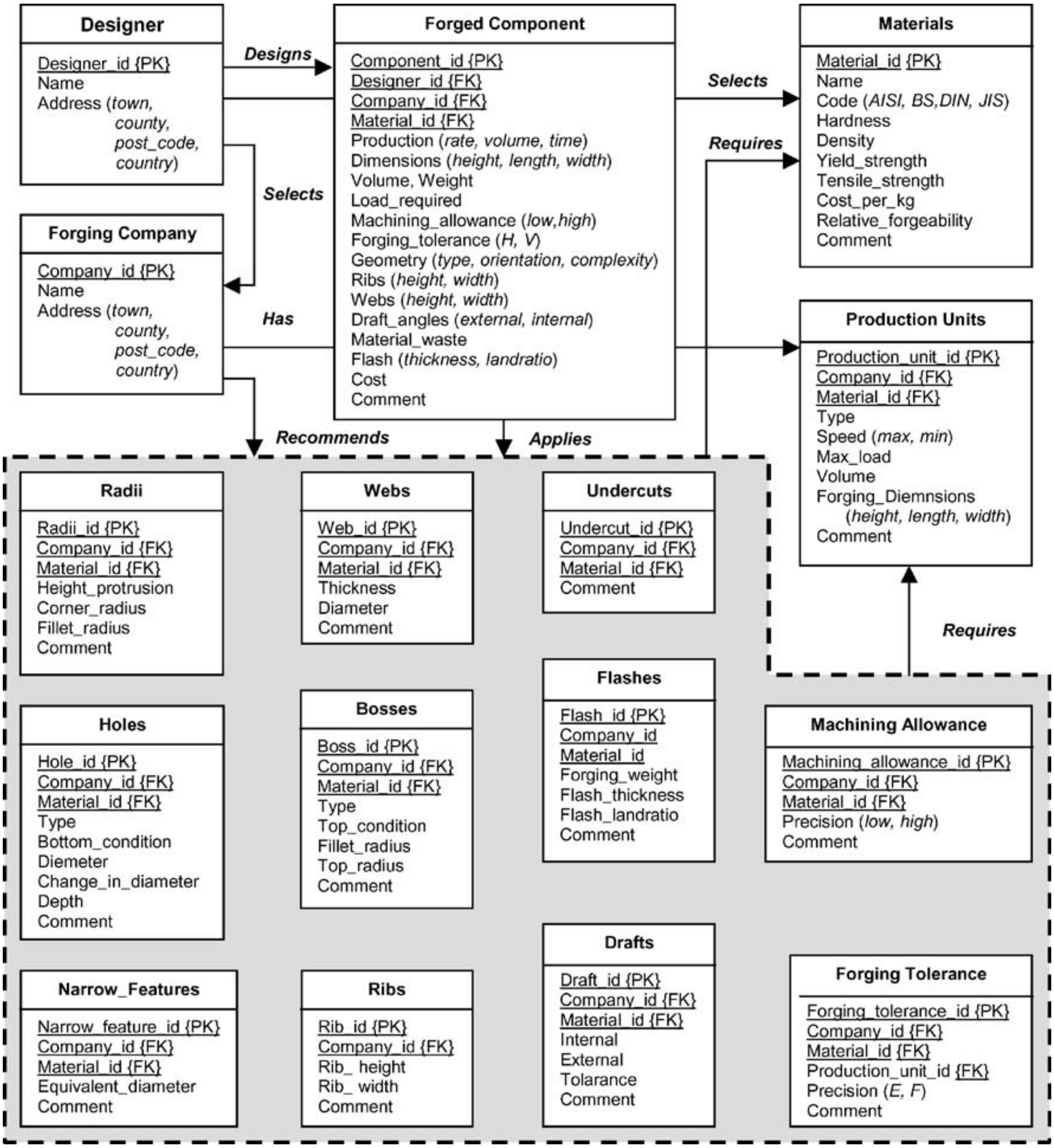
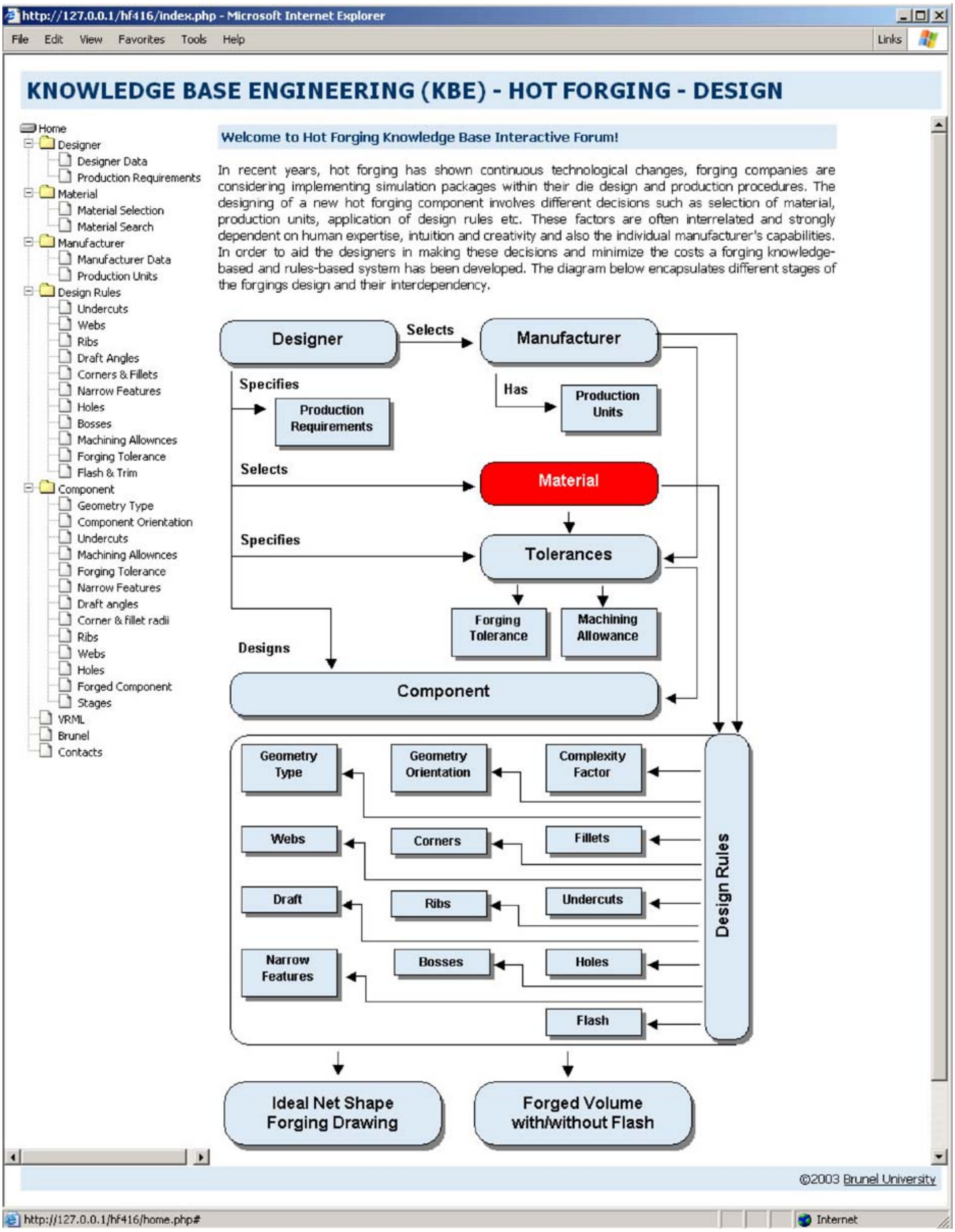


Fig. 4 Integrated database of materials and design rules

NURBS surface and solid modelling libraries will add new powerful surface and solids capabilities to GDL's built–in 3D wireframe facilities [16].

4.2 Integrated database of materials and design rules

The schematic diagram of the integrated database system is shown in Fig. 4. The database of the KBE application is



KNOWLEDGE BASE ENGINEERING (KBE) - HOT FORGING - DESIGN

Welcome to Hot Forging Knowledge Base Interactive Forum!

In recent years, hot forging has shown continuous technological changes, forging companies are considering implementing simulation packages within their die design and production procedures. The designing of a new hot forging component involves different decisions such as selection of material, production units, application of design rules etc. These factors are often interrelated and strongly dependent on human expertise, intuition and creativity and also the individual manufacturer's capabilities. In order to aid the designers in making these decisions and minimize the costs a forging knowledge-based and rules-based system has been developed. The diagram below encapsulates different stages of the forgings design and their interdependency.

Fig. 5 User interface

designed as an independent separate part of the whole system containing the design rules, production units' specifications and material properties.

Knowledge (design rules) has been obtained from handbooks, plasticity theories, relevant references and empirical know–how of field experts in hot forging companies. The database also takes into account the dependency of the design rules on materials, production units (such as a mechanical press, screw press, hammer etc.) and component geometry (such as axisymmetric, plain strain, 3D etc.). Rules are arranged in the form of tables or equations.

4.3 User interface and visualisation

The browser-based user interface for accessing the design knowledge is shown in Fig. 5. The tree menu on the left allows the selection of several expandable submenus, which in turn update the main viewing window to guide the user interactively through the design process.

The same can be achieved by using the block diagram, shown in the main window in Fig. 5. Various boxes represent different design decisions and guidelines, which are being implemented in the system, such as material selection, determination of component geometry, parting line, specification of appropriate radii, internal and external drafts, design of holes, ribs, webs etc. Most of the web pages consist of information entered directly using standard HTML form objects. Visualisation of the component geometry on the client's machine is achieved using the Virtual Reality Markup Language (VRML) [17]. The VRML is currently the best way to create interactive, 3D environments on the WWW. VRML is generally viewed within a web browser like Netscape Navigator or Microsoft Internet Explorer. These browsers do not support VRML natively, therefore a plug-in such as Cosmo Player is required to view VRML content.

5 Summary and conclusions

This paper presented the preliminary stage of the development of a KBE system for hot forging design using state–of–the-art KBE technology and the Internet. Instead of trying to fully automate the forging design the KBE leads designers through the design process and enables appropriate manufacturing rules as well as company capabilities to be complied with. The key feature of KBE application is that it integrates the whole design process within one computer model. The relational database is used to encapsulate the design rules as well as their complex interdependencies on material, production unit, and manufacturer capabilities. Design rules have been obtained from handbooks, plasticity theories, relevant references and empirical know–how of field experts in hot forging companies. The KBE also takes into account the dependency of the design rules on materials, production units (such as mechanical presses, screw presses, hammers etc.) and component geometry (axisymmetric, plain strain and 3D). The work is ongoing aiming at further implementation of design rules, transfer of simulation results as well as the storage and retrieval of a large number of case studies.

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