Intelligent Design Agents With Integral Design Knowledge

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Abstract

Intelligent Engineering Design Assistants (EDA) are smart agents that help in the solution of many complex engineering design problems. EDA are based on the idea of reducing the complexity of design process and providing the machine design knowledge to the CAD environment to reduce the reliance on the knowledge of a skilled user. EDA represent another interesting application of the agent technology within CAD domain. EDA are classified depending on their application and use. The present paper illustrates the design and use of an EDA for the design data calculations for gears with minimal dependency on the designer's skills. The Gear Design Agent (GDA) – a demonstrated EDA is designed to perform the design data calculations for gears and providing associated design knowledge to the user. The output from GDA is transformed into a geometry model and can be exported for manufacturing directly.

Keywords: Intelligent Design Agents, Integrated Knowledge, CAD application, Gears,

1. Introduction

As a result of the digital revolution in the design world in last decade, the CAD environment is facing really complex challenges. The design activity is no longer restricted to just designing a part using a computer. It has reached a level of complexity where the user expects complete assistance from concept to post production support level. This has led to considerable amount of data generation and high reliance on the user skills. Unlike earlier days, the complete design activity has become quite complex as it has to address the Product Lifecycle Management (PLM) issues and deserves simplicity. Some of the major challenges are managing the complexity of the overall design process and the life cycle patterns for the product being designed. Large number of parts, complex geometry, parts exhibiting multiple functions, ambiguous requirements, diverse knowledge and expertise associated with particular design are factors that add to the complexity of design. A methodology for addressing these issues is explained in the data complexity management concepts [3]. One of the ways to make it simpler is to make the system itself 'intelligent' and user friendly so that the requisite skill level of the user can be reduced. Traditionally, a highly skilled user has always been an indispensable constituent of any CAD system. This particular need makes the overall system person dependent – not a desirable feature in the world of global activities.

There had been continued efforts to make the CAD systems efficient and user friendly. However, the need for the user's knowledge of mechanical and machine design could not be dispensed with. An Engineering Design Assistant is one of the promising tools for a variety of design complexity problems that exist in a CAD/PLM environment. Engineering Design Assistants work as 'intelligent modules' inside the CAD system that make the environment smart and more efficient. An agent or an assistant is a computer system situated in some environment that is capable of flexible autonomous action in order to meet its design objectives [1]. Engineering Design Assistants are of different types such as, *data agents, checking agents, monitoring agents, analysis agents,* and combinations of two or more types. They are static as well as dynamic in nature depending on the functionality and requirement.

EDA are created along the lines of complexity management concepts and are interactive in nature, empowering the user with significant flexibility with the design. These agents are expected to perform the design data calculations considering all the possibilities in the process.

This paper presents a representative example of Gear Design Agent that works as an integral part of an experimental CAD system, Alpha_1. GDA can also work as a standalone application in the Linux and/or Windows environment.

Subject work presents a combination of the complexity management concepts [3] and the Agent development activity [2] aimed at better system performance.

2. Need of Design Data Calculations

In any machine design problem there is a basic need for the associated design data. Design data is calculated suitable for the purpose of the part under design considerations. This involves input in terms of various parameters and working conditions. Depending on the requirements, it is designer's job to generate data for the best possible design, one that is ready to manufacture. The appropriate parameter consideration comes from the knowledge and experience of the designer.

Gears are one of the most important and common mechanical parts in any assembly involving power transmission. Gears are meant for transmitting the power at the desired speed. Gear design is a very complex activity involving many input parameters and operating conditions. The GDA performs the design data calculations and also provides associated design information to the user in a highly interactive manner. The output from the agent is such that it can be readily transported for generating a corresponding geometric model of gear, which can be viewed with TK3d graphical editor. The GDA is designed such that it can be used for a fresh design as well as in reverse engineering applications.

3. Issues Related with the Gear Design Process

In process of gear design, the key factor is to select a tooth profile and suitable material properties. The gear tooth strength represents the strength of the gear being designed. When a gear is designed, the gear tooth is designed to resist the bending failure as well as pitting failure of the tooth surfaces.

The projected stress strain relationship serves as a fundamental to estimate the core dimensions and design properties. The geometry of the component is decided by the data generated by basic and derived calculations. Apart from the theoretical considerations, there are certain other factors such as working conditions, safety and cost, which need to be incorporated.

4. Design Related Considerations and Assumptions

Gears designed for any application are such that they will sustain acting loads at any given point of time and loading condition with a considerable amount of associated safety.

To ease the complex design process, a systematic approach based on the design principles and assumptions is followed. In GDA, the prime gear design parameter is *module*. A little consideration shows that module is the index of tooth size and ultimately gear strength also. Other important feature is that, most of the design parameters for a gear such as, working depth, clearance, addendum and dedendum, gear ratio, face width, pitch diameter, etc., are normally expressed in terms of module.

When a gear pair has to be designed, it is of prime importance to calculate the minimum value of *module* for safe operation. Once the safe working value of *module* is obtained, other design parameters can be easily derived. In GDA, the basic functionality is to calculate the minimum value of *module* using bending fatigue and surface fatigue stress calculations. In a conventional design practice, the input data for the design calculations is obtained from the design data handbook or the empirical relationships established as standards or more frequently from the experience and expertise of the designer. This is exactly what makes design process highly dependent on user skills.

5. How GDA Works

GDA is designed to work in the context where the working conditions and the specifications in terms of power or torque transmission and speed are known. The design algorithm used in GDA follows the guidelines of American Gear Manufacturers' Association (AGMA) standards with appropriate assumptions where necessary. The purpose of the GDA is to add knowledge to the application that traditionally would have been provided by a skilled user. Depending on the user's choice, the GDA selects the corresponding design algorithm automatically.

Next level is to input the parameters and working conditions for design data calculation. For every input parameter, the user can seek help from the *More Info* feature, which provides the definition and relevance of the subject design parameter. Wherever applicable it also provides the empirical relationships with other relevant parameters and ranges of values. This is achieved with the interactive Graphical User Interface (GUI) provided on top of the GDA application. Related knowledge for the design parameter is made available to the user when asked for *More Info*. *More Info* section of the utility is the area where machine design knowledge is stored and gives an opportunity to reduce the need of skilled user as designer. The screenshot of the working of pressure angle input and *More Info* for pressure angle input is shown in Figure 1 and 2, respectively.

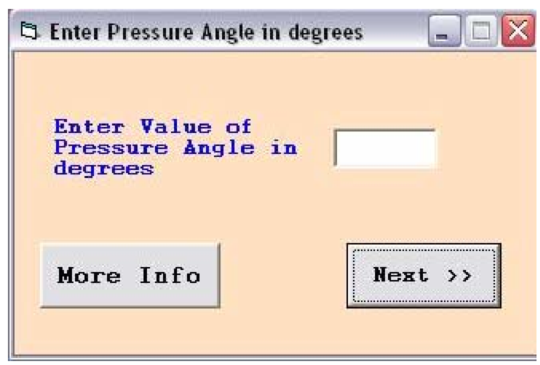

Figure 1: Screenshot of Pressure Angle Input Window

After running one complete cycle of the agent utility, the designer gets the output in the form of basic design parameters that lead to the generation of a geometry model. The utility presents the data in the format that can be readily used within the Alpha_1 experimental CAD/CAM system. The graphical representation of the designed gear can be viewed using TK3d. Figure 3 shows the screen shot from TK3d showing a spur gear model designed using GDA.

If the designer is not satisfied with the outcome with the given set of input parameters, the designer gets an option to try the procedure again without restarting the utility again. Another associated advantage with this is that the user can see the value of input parameters used in the preceding iteration (provided the utility is running in a second or subsequent iteration).

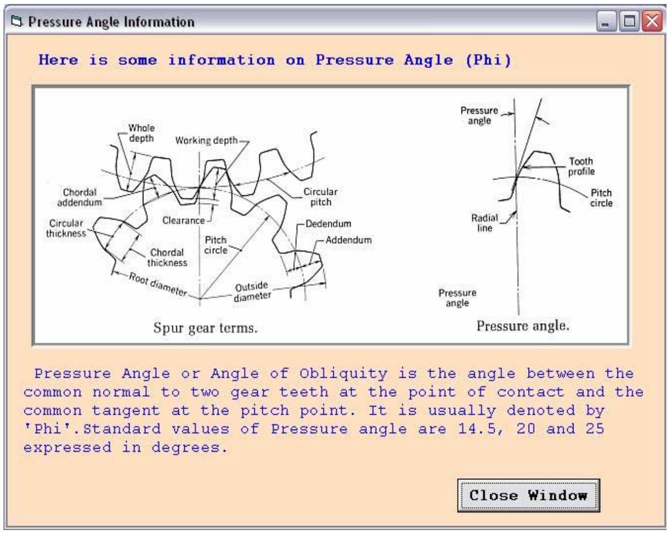

Figure 2: Screenshot for More Info on Pressure Angle

Once the geometry model is confirmed by the user, it can be exported to FeatureCAM™. FeatureCAM™ will generate the NC code for manufacturing prototype gears using Wire EDM.

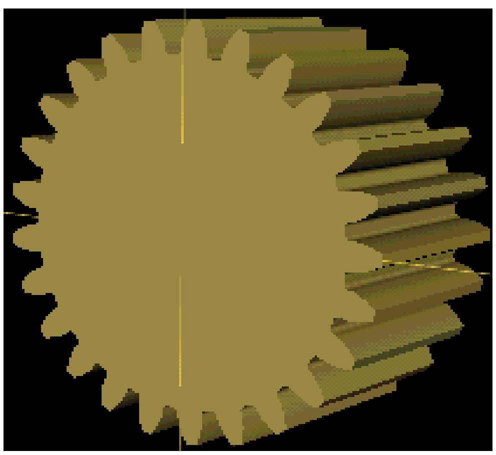
Figure 3: Screen shot for Spur Gear model designed using GDA

6. Design Algorithm

The algorithm embodied in the design utility follows the standard gear design procedure using varied parameters as suggested by AGMA. The calculation sequence being standard is not discussed here in detail. Values of *module* obtained from bending calculations and surface fatigue calculations are compared with each other and it is confirmed that the value of module for surface fatigue method is more than that for the bending stress approach.

Generation of accurate gear profile is important for uniform motion at a constant velocity. The correct gear profile will ensure that gears mate such that the common normal to the tooth profile at the point of contact will always pass through the pitch point for a given constant velocity ratio. The single tooth profile is generated to get an accurate involute gear tooth profile. Instead of a line-arc representation, a set of control points is used through which a curve is passed resulting in an accurate profile. GDA gives output in a format that can be used directly in the Alpha_1 environment to generate an involute gear profile. Single tooth profile is created which is rotated around entire circumference of the pitch circle for the number of teeth on the gear. The 2D curve generated, can be regarded as an assembly, design and a machining feature. A profile stock can be created with this curve giving an accurate representation of the spur gear. This curve can be exported to a CAM environment where an appropriate wire EDM tool-path can be generated for manufacturing prototype gears using FeatureCAM™. A similar approach is used for design data calculation for the helical gears. Implementation of similar modules and functions is unique to the Alpha_1 CAD/CAM system, as most of commercial software products concentrate on the concept design for manufacturing and the development of machining features.

7. Features of GDA

Apart from the automation of the design data calculation process, what makes Gear Design Agent unique is the design knowledge offered to the user by means of an interactive GUI. Additional information about the input parameters is available at a mouse click.

The GDA has another advantage in terms of presenting information to the user that has certain advantages such as faster and better design with lower possibilities of design conflicts. The architecture of GDA is very portable and can be altered for other design elements such as bearings, shafts, etc. Data generated by the GDA can be used as source data by other agents in the system. This can be looked as a multi-agent environment where the data generated by one agent is used for other agent activities. The data can be used to address the cases of design conflicts or dependencies. In such situations the data generated by the respective agents is accessed by the monitoring agent and the user is alerted to the possible conflict.

There are attempts to incorporate the knowledge base within the CAD system itself as in CATIA V5. They have introduced the features of Knowledge Based Engineering (KBE). However, GDA is different from KBE though it may appear somewhat similar. KBE features are more into the design refining tools like Dimension Measurement Tool, Ground Clearance Tool, Suspension Analysis Tool, Tire Clearance Tool, etc. [5]. These tools do not address the very process of part design thoughts. These tools are helpful for the full product details which may not otherwise be required for all the design activities. GDA addresses the actual design process and provides the necessary design knowledge to the user. It does not work on top of already designed components to verify certain aspects of the product.

8. Conclusion and Future Work

GDA can be viewed as a demonstrated example of smart 'Engineering Design Assistants' in the CAD framework. Similar agents can be created for other mechanical parts or assemblies that add the machine design knowledge into the software environment. The interactive GUI associated with the agents is highly user friendly and reduces the need of a skilled user. These agents work as an integral part of the CAD system but also have the capability to work in stand alone mode. This allows GUIs to be inserted in web based applications also.

GDA is a classic example of the automated intelligent agents as discussed by Jennings, Sycara, and Wooldridge [1] and W Shen, Jen-Paul, A Barthes, [2] in the CAD domain. GDA is a 'practical reasoning agent' that is inspired by a theory of pragmatic reasoning in humans used to decide what to do. Autonomy in the gear design process is otherwise a difficult concept to pin down precisely, but we mean it simply in the sense that the system should be able to act without relying on the user skills to perform and should have the control over its own actions and internal state. We perceive it as a step in the direction of agent based CAD/PLM system structure conceptualized in terms of agents design and implemented by acknowledging the existence of agents. GDA is something more than mere programming functions that can be used across the system; it has an embedded, integral knowledge base. GDA is an agent that could take initiative in the complex design steps to make the overall process easier and liberate the user with the need of certain mandatory skills. GDA falls in the category of 'expert assistants' operating as a semi-autonomous agent as defined by Jennings, Sycara and Wooldridge [1]

These different agents can be integrated together to establish the information network across the system. Most importantly these agents are easy and time saving to build than whole system addressing the similar needs.

Populating such assistants within the existing system will make the system dynamic. Also, the network of such design agents will be helpful in creating dynamic Engineering Design Documents. Other types of agents like analysis agents or monitoring agents e.g. can be developed along similar lines. However, for better results and efficient response, the system has to support the functioning of these agents within itself. For this purpose there is a need of building a system structure which includes agents in its core as native and integral elements. Such designed systems are expected to replace the existing systems and lead into the intelligent environment.

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9. References

[1] Nicholas R. Jennings, Katia Sycara, Micheal Wooldridge, 'A Roadmap of Agent Research and Development'.

[2] W Shen, Jen-Paul, A Barthes, 'An Experimental Multi-Agent Environment for Engineering Design'

[3] Jacobs, Tim, M. 1998, 'An Automated Framework for managing Design Complexity Draft' Ph. D. Thesis, University of Utah, Salt Lake City, UT.

[4] Baker, B. A., Fish, Russ D., Cohen Elaine, 'Using Multiple Concurrent Design Views Interface to Enhance Design Complexity Management', Proceedings ASME Design Engineering Technical Conference, ASME, DETC2000/DAC-14261, Baltimore, MD.

[5] CATIA V5, Knowledge Based Engineering (KBE) documentation

[6] Amol Deshpande, 2004, Smart Design Agents for Complex Systems with Integral Design Knowledge, Masters Thesis, University of Utah, Salt Lake City, UT

[7] Loss, B. F., 1997, 'DRIVE: A system for Interactive Review of Engineering Design', Masters Thesis, University of Utah, Salt Lake City, UT.

[8] Shigley, Joseph E. and Mischke Charles R. 2001, 'Mechanical Engineering Design (in SI Units)' sixth edition, Tata McGraw Hill Publishing Company Limited, New Delhi.

[9] Juvinall, Robert C. and Marshek, Kurt M. 1991, Fundamentals of Machine Component Design, John Wiley and Sons, New York

[10] Kapelevich Alexander L., and Kleiss, Roderick E., Gear Technology September / October 2002 'Direct Gear Design for Spur and Helical Involute Gears', www.geartechnology.com .

[11] SHOPSWARF, New Zealand http://shopswarf.orcon.net.nz/spur.html

[12] S Rajagopalan, J.M. Pinilla, P. Losleben, Q. Tian, and S. K. Gupta "Integrated Design and Rapid Manufacturing Over the Internet." presented at Proceedings of DETC'98, 1998.

[13] M.R. Danesh and Y. Jin, "ADN: An Agent Based Decision Network for Concurrent Design and Manufacturing," presented at the proceedings of DETC'99, Las Vegas, NV, 1999.

[14] J. Shah, M. Mantyla, "Parametric and Feature Based CAD/CAM, 1995

[15] G. Pahl and W. Beitz, 'Engineering Design – A systematic Approach:' Springer-Verlag, 1998.