Proceedings of the 7th WSEAS International Conference on Automation & Information, Cavtat, Croatia, June 13-15, 2006 (pp32-37)

Catalogue-Based Bearing Design by Capturing Mechanical Design Knowledge and Experience

APICHART SUPPAPITNARM
The National Metal and Materials Technology Center (MTEC)
National Science and Technology Development Agency (NSTDA)
114 Paholyothin Road, Tambol Klong 1, Klong Luang, Pathumthani
THAILAND
http://www.mtec.or.th

Abstract: - With strategies in knowledge and experience capture in relevant industries, this paper describes the development and implementation of efficient search technique for mechanical component selection, and demonstrate its application in the selection of bearings. The research was conducted in two mechanical design companies with a cooperation from a bearing supplier company in Thailand as part of the knowledge management project under the grant of National Science and Technology Development Agency (NSTDA), in fiscal year 2004. Following findings with empirical research methods, a computational tool was developed in line of designers' behavior patterns so that using the computer program not only helps designers in the selection process but also encourages the design activities as using the tool is not an annoying task. The proposed support tool could help new generation designers to think and develop the bearing selection process by themselves, accumulate design skills and hence promotes their creativity. Besides, such a computer program could be a good tool for practice for engineering students in relevant fields. During the evaluation period of the support tool with the final-year undergraduate students in mechanical engineering department, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand, the students' reaction was very positive. The programming structure of the computer tool can be applied to the development of support tools for other similar mechanical components such as gears and chains, and, finally leading to the development of a total expert system for mechanical design.

Key-Words: - Design knowledge, Knowledge and Experience Capture & Reuse, Design Strategies, Bearing Design, Design Support Tool

1 Introduction

Many companies in the competitive world now recognise the need to know what is already known in their organisation and make maximum (re)use of their knowledge [1]. Recently, many tools have been developed to support designers. Tools that capture engineering design knowledge can be classified as off-line capture and on-line capture [2]. Off-line tools do not capture knowledge as part of the design process, but the knowledge is managed and structured by people who are specifically employed to do so. On-line tools capture the knowledge during the design process. The designers spend additional time capturing the design rationale while updating the structure of the knowledge being captured.

Machine design and mechanical component selection is a complex engineering task that deserves a good case study for knowledge management for years. As a result of its many considerations, several standard handbooks and engineering manuals for the machine design and component selection have been published, revised, and expanded constantly to reflect important technological developments. Despite these handbooks offer valuable knowledge resources to designers, their practical use is extremely limited in industries. This paper describes an attempt to develop a more practical tool satisfying needs by designers using an empirical approach in knowledge and experience capture.

2 Current Understanding of How Designers Design

In order to understand how to support designers, research into how designers approach their tasks were reviewed. It was found that the level of experiences gained by the designers contributes to a distinct pattern in the design thinking and design activities. Novice designers were found to have a tendency to reason backwards and to use a deductive approach. Experienced designers, on the other hand, tend to reason forwards, and, when solving more complex problems, to alternate between forward and backward reasoning [3, 4, 5, 6]. In addition, experienced designers were found to hold larger amounts of information in a single chunk of memory and to have better spatial memory than novices [7, 8]. Experienced designers are able to reproduce engineering drawing by drawing at a time for longer before referring to the original [9]. As the design evolved, the behavior of the experienced designers moves from systematic to opportunistic [10]. This suggests that designers tend to move towards a heuristic approach to design. Experienced designers also adopt design strategies while carrying out their design tasks [11]. These strategies could be identified as design knowledge which must be captured and reused for future design activities.

3 Development of a Computational Tool for Catalogue-Based Bearing Design

3.1 Identifying Target Industry and Area under Scope

Mechanical design is one of the major industries among the Thai small and medium enterprises (SMEs). While this is true and many companies employ several well-educated mechanical designers and engineers, design knowledge has been lost from generation to generation as there is no a proper way to capture and accumulate such knowledge. In machine design, bearing is one of critical elements that is used extensively to reduce friction in many design applications. Bearing selection is quite a complex task and can require many considerations in its process. Therefore, it can be a good and interesting case study for a knowledge capture project.

3.2 Identifying Engineering Design Knowledge

To capture design knowledge, an empirical research approach using observations, discourse analyses and interviews were conducted in the mechanical design industries:

Observation into how the designers do their tasks can provide a surface understanding of the differences between novice and experienced designers. This will initiate how the development of the support tools should be carried out.

Discourse analysis is performed to capture the knowledge needed by each designer through the interactions (in form of questions, comments, statements etc.) among their colleagues while solving their design problems. The discourse analyses provide a deeper understanding into the differences between the novice and experienced designers, for example, to identify the types of questions asked by novice designers and their awareness of their knowledge (and what form) needs.

The interviews are used to confirm the findings from the other two methods once the structure of the supporting tools is developed. While the discourse analysis pays more attention to the questions asked among the designers, the interview focuses on the answers to the questions get asked by the investigator. The interviews also provide an insight into each industry practice and a broad view of the design projects undertaken by the designers.

3.3 Participants

11 engineering designers from two bearing design companies agreed to participate in the study. They were all men, with working experience in bearing design ranging from a few months (novice) to several years (experienced designers). The observations and discourse analyses were conducted at the designers' working sites so as to provide a suitable environment with a researcher being there to collect data. The use of a designer's own environment and a real design task has the advantage of being closer to a real-life situation. All the designers were asked to think and act aloud for every step of their activities. The interviews were used at last to confirm the findings from the observations and discourse analyses. As it was observed that many designers referred to a few bearing suppliers many times during the design and selection process, the interview was then conducted with two representatives from a bearing supplier company to find out more information.

3.4 Findings from Empirical Research

The findings from empirical research reveal many interesting observations. In particular, these findings for mechanical design industry were in line with that suggested by Ahmed [11] in that engineers with less working experiences (novice) were found not to develop the design strategies during their activities. However, not all the experienced developed every strategy identified by Ahmed, especially on question data about bearing specifications. However, they referred to past designs or previous projects if the same bearing parts were used. They were also aware of limitations of some design tasks and were aware of arising drawbacks if they chose a particular part over another.

It is interesting to observe that both experienced designers and novices, on several occasions, called their counterpart bearing suppliers during their design and selection process, but for different reasons. While the experienced designers asked the suppliers if the bearing parts with some desired properties were available, the novice designers asked for help directly on their design projects. It is clear that the novices tended to shift their design responsibilities to the counterpart suppliers. Findings from the interviews confirm that because of industry culture, the designers normally start their jobs (as novice) by interacting mostly with their bearing suppliers who act like their supervisors or trainers during their early years in industry. As the designers gain more experiences, they can handle design projects more independently (moving from novice towards experienced designer behavior) and the interaction between the engineers and suppliers finally reduces to only querying for part availability. It is interesting to note that in stead of transferring from the experienced to novice, the design knowledge is always transferred through the suppliers outside the company. The novice designers felt that they could get a solution more quickly with their suppliers while this also kept interrupting time on the experienced to a minimum. In particular, the novices thought that the experienced designers know what the suppliers know but this knowledge is implicit and is gained only by accumulating experiences in industry. The experienced designers agreed that they might have possessed some design strategies but these cannot be made explicit.

3.5 A Computational Tool for Catalogue-Based Bearing Design

The method aimed to give the meta-knowledge to the users by simulating the selection process and encouraging the users to experiment with the method to find matching bearing parts. Database from standard bearing catalogues was in line with the computer program so that only the parts available through suppliers were presented. This eliminated the necessity to open up the manual catalogue or to call the suppliers to check for part availability.

Fig.1 shows the system architecture of the proposed framework of the support tool. The system architecture has three tiers. The data tier allows the users to retrieve a database by specifying a database name, host or server name and a security type. Structured Query Language (SQL) is a language of choice for database retrieval and can reduce unneccessary querying structures of programming code significantly. The use of SQL is becoming more popular in database search application in recent years particularly as many SQL versions have been developed with more embedded functions.

The presentation tier supports the windows user interface. The middle tier serves as a bridge between DataSet (in presentation tier) and the database (in data tier) by sending the command to retrieve the required set of data.

The structure of bearing database is shown in Fig.2 Each type of bearings can require numerous and different design considerations which can result in a large number of fields in the database. For ease of illustration, only 3 fields are presented for deep groove ball bearings as examples. Users can select any number of the required fields, and in any order, to search for the parts. For example, if a user initially selects a required dynamic load of 1100 N (step 1),

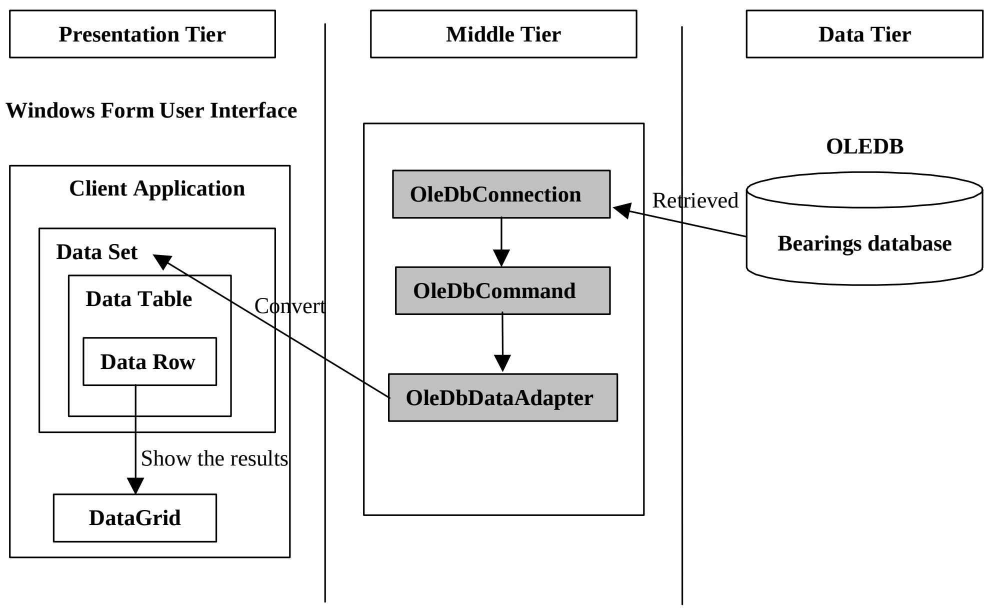

Fig.1. System architecture of the proposed framework

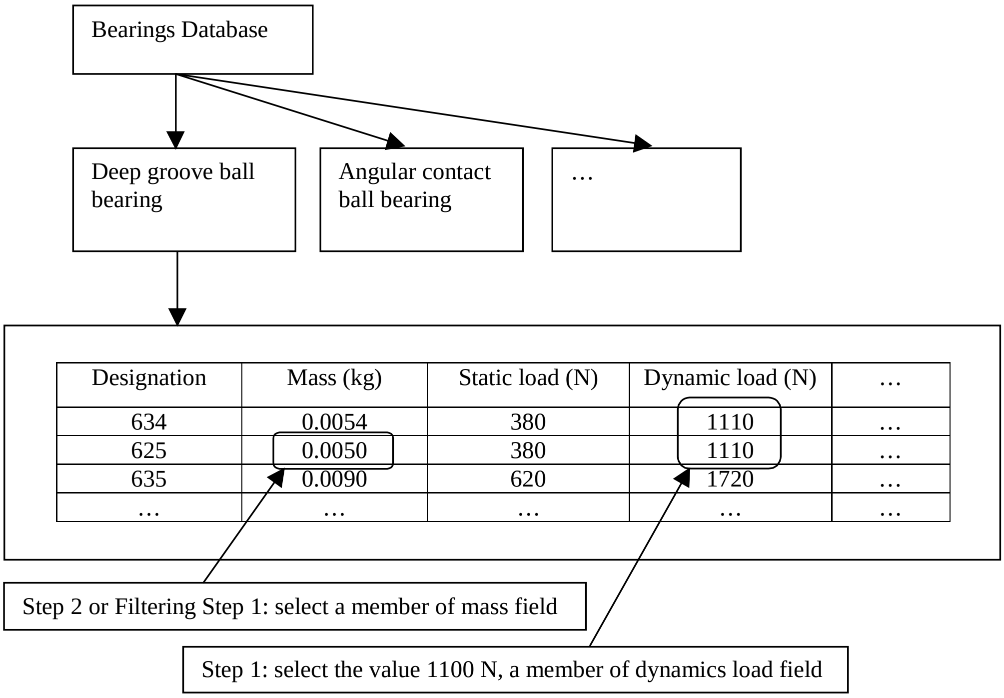

Fig.2. Structure of bearing database and illustration of filtering mechanism

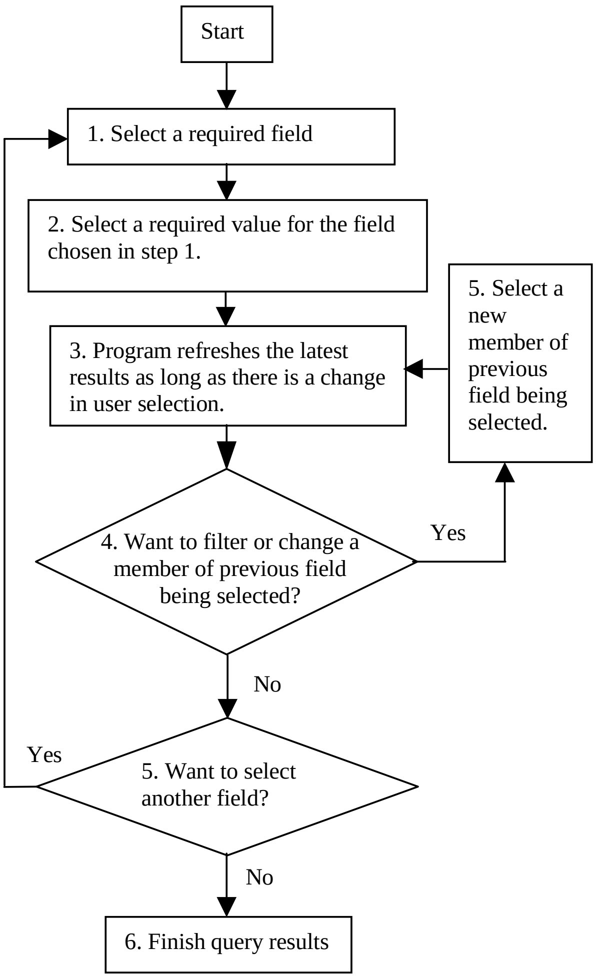

Fig.3. Flowchart of operating instructions to use the program

after an SQL statement is evaluated, both parts with designations 634 and 625 will be shown available. However, if a user would like to filter the search further with the required mass of 0.0050 kg (step 2), the results are then refreshed immediately and only the part with designation 625 will be available.

Note that the search results are always interactive and real-time with the latest set of requirements that have been specified in the SQL query. Fig.3 summarizes the search and filter mechanism as a flowchart of instructions for the users to use the program.

Regarding the selection for suitable types of bearing for various design applications, the user is aided with a tool similar to that shown in Fig.4, which is an example for bearing design for electrical motors. Other knowledge-based tools for bearing type selection have also been developed for a variety of common applications frequently encountered by the design engineers. Once the user retrieves a suitable type of bearing for the application, he/she can go directly to the bearing catalogue to perform the search selection as outlined above.

Fig.5 shows a main window of the computer program for bearing selection based on the nine parameters that the experienced designers seemed to use most during their design task. In the case of bearing specification, a user can select, query and change any parameter while searching for the parts interactively until he/she gets satisfied results. This real-time displayed results can help the user for better selection in the proceeding step as needed.

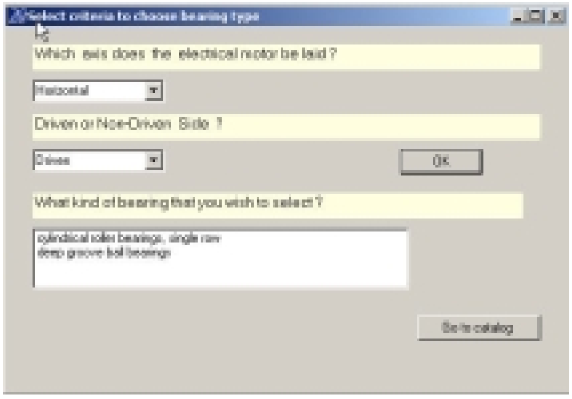

Fig.4. Bearing type selection for electrical motor applications

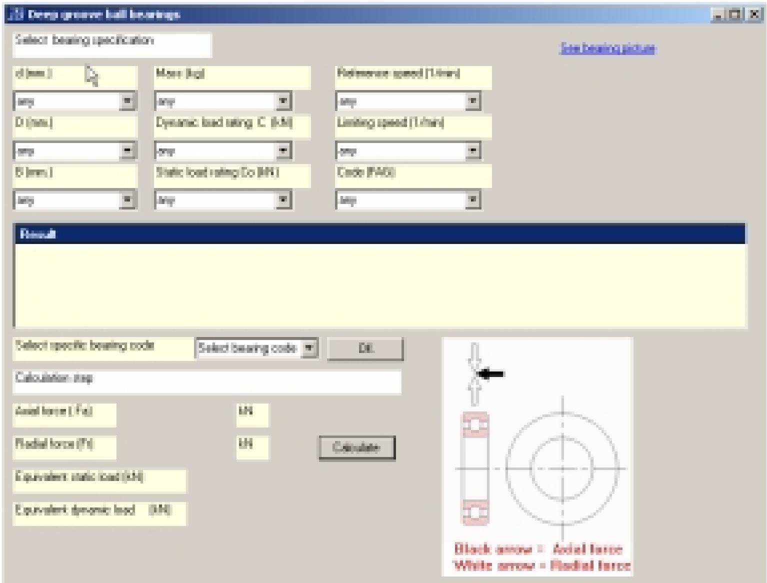

Fig.5. Example of program main window for bearing selection (deep groove ball bearings)

4 Evaluation of the Support Tool

The evaluation consisted of three parts: 1) a twenty-minute introduction to the support tool and to the evaluation procedure; 2) a one-to-two-hour observation of a designer/student using the tool; and 3) a post-evaluation interview.

4.1 Evaluation by the Design Engineers

All the design engineers were informed that the output of their design work would not be evaluated and it was only intended to evaluate the support tool. The designers were asked to carry out their normal design task and to use the support tool. They were not allowed to contact their counterpart suppliers unless they felt it was so necessary and a reason must be given in such case. However, discourse activities were permitted. The novice designers were informed that they were able to ask any question to the experienced designers. The experienced designers were requested to answer all the questions and, if exist, to write down any inappropriate questions asked by the novice designers.

The novice and experienced designers were asked to give their comments to the support tool after the task. All the novice designers' comments were positive and generally enthusiastic. Many experienced designers felt that using the program sometimes delayed their design decision. However, it was useful for searching for standard parts at the last stage of the selection process – the process they normally approach their counterpart suppliers. None of inappropriate questions was reported, although there were only a few questions raised by the novice designers. All novices mentioned that the method was a useful design aid whereas many experienced designers commented that the program offered a convenient way to open up a catalogue and its pre-interfaces could be a good tool for learners. One experienced designer reported that he still preferred to call a supplier for a quote as there was no guarantee if the standard part found by the electronic catalogue would really be available. It is anticipated that if the electronic catalogue of the support tool is online or can be linked directly to the supplier websites, the support tool can offer an easy, convenient and reliable way to search for suitable bearings for various designers' applications.

4.2 Evaluation by Final-year Engineering Students

As part of the machine design course at King Mongkut's Institute of Technology Ladkrabang, Thailand, students were normally divided into groups, each carrying a project for their chosen design applications. After the support tool was introduced to the students, a few groups of students volunteered to use the support tool while carrying their design activities. All students (both using and not using the tool) were allowed to open up any books, manuals and to look up any information from the websites. They were, however, requested to report any finding or any reference they used in deriving a decision on the bearing selection. The output of their design work was assessed for each group by the course instructor.

It was found that the quality of design outputs for the students using the support tool was comparable to that for those not using it, although the latter seemed to have many references on their design decisions. This indicates that without the support tool, the students must seek and access many sources of information in order to succeed in their design task. The reaction of students with the support tool, based upon their comments, was found to be positive. The students felt that they had learnt a lot from the tool and had saved a lot of time on the task with the tool provided. One student mentioned that 'somebody has picked up all the information that one should be asking for. The tool works like a one-stop shop for bearing design'. Two other students commented that the tool should be extended to support the search and selection for other machine design elements such as gears and chains as these could be considered and used frequently during the design activities.

5 Conclusions

Although many industries and organizations have recognized the importance of the (re)use of their knowledge, the tools to accomplish such capture, development and delivery have just only become available. This paper outlines some existing approaches for knowledge support tools and presents a computational framework for catalogue-based bearing design as a case study.

Results from the empirical research had led to the development of a support tool consisting of many computer programs that aim to reduce the complex selection task in standard bearing selection. These include the bearing type selection for a variety of design applications and the bearing selection from an electronic catalogue based on some key design parameters. Evaluation of the tool suggested that the tool is a good learning source for novice designers and offers a more convenient way to access a bearing catalogue for more experienced designers. The proposed tool could help novice designers in carrying a design task and has allowed them to think and develop the bearing selection process by themselves, accumulate design skills and hence promotes their creativity. This eventually could help eliminate the habit or culture of supplier dependency. That is, the novices' working behavior can be trained to move towards the experienced designer pattern with the support tool without assistance from their usual counterpart suppliers. The program could also be a good tool for practice for engineering students in relevant fields. During the evaluation period of the support tool with the final-year students at King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand, the students' reaction was very positive. The programming structure of the computer tool can be applied to the development of support tools for other similar mechanical components such as gears and chains, and, finally to the development of an expert system for mechanical design.

References:

[1] Miller, W.L. and Morris, L., *Fourth Generation R&D – Managing Knowledge, Technology and Innovation*, John Wiley & Sons, 1999.

[2] Jensen, T., Capturing and Reuse of Design Knowledge during the Conceptual Design Process: Illustrated with a Snap-Fit Joint, in *Computer Aided Conceptual Design Workshop (CACD'98)*, Lancaster, UK, 1998.

[3] Jong, de, A.J.M., Kennis en het oplossen van vakinhoudelijke problemen (Knowledge and Solving Domain Problems), Technical University of Eindhoven, Eindhoven, The Netherlands, 1986.

[4] Christiaans, H.H.C.M., Creativity in Design: The Role of Domain Knowledge in Designing, Lemma Bv, Urecht, 1992.

[5] Ericsson, K.A. and Charness, N., Cognitive and Development Factors in Expert Performance, in P.J. Feltovich, K.M. Ford and R.R. Hoffman (eds), *Expertise in Context*, AAAI Press, California, pp. 3-41, 1997.

[6] Zeitz, C.M., Some Concrete Advantages of Abstraction: How Experts' Representations Facilitate Reasoning, in P.J. Feltovich, K.M. Ford and R.R. Hoffman (eds), *Expertise in Context*, AAAI Press, California, pp. 43-65, 1997.

[7] Gobert, J.D., Expertise in the Comprehension of Architectural Plans (Knowledge Acquisition and Inference-Making)", in J.S. Gero and B. Tversky (eds), *Visual and Spatial Reasoning in Design*, Sydney, pp. 184-205, 1999.

[8] Göker, M.H., The Effects of Experience During Design Problem Solving, *Design Studies*, Vol. 18, pp. 405-426, 1997.

[9] Waldron, M.B., Jelinek, W., Owen D. and Waldron, K.J., A Study of Visual Recall Differences Between Experts and Naive Designers, in W.E. Eder (eds), *International Conference on Engineering Design (ICED'1987)*, pp. 1090, 1987.

[10] Stauffer, L.A. and Ullman, D.G., A Comparison of the Results of the Empirical Studies into the Mechanical Design Process", *Design Studies*, Vol. 9, pp. 107-114, 1988.

[11] Ahmed, S., Wallace, K.M. and Blessing, L.T.M., Understanding the Differences between How Novice and Experienced Designers Approach Design Tasks, *Research in Engineering Design*, Vol. 14, No. 1, pp. 1-11, 2003.