USING MENTOR™, AN EXPERT SYSTEM, TO PERFORM PREVENTATIVE MAINTENANCE AND DIAGNOSTICS ON CENTRIFUGAL CHILLERS.

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ABSTRACT

Mentor™ is an expert system which was developed and introduced in 1986 assists service refrigeration techs to perform the correct preventative maintenance (PM) and diagnostics on centrifugal chillers at the right time. This expert system has undergone several upgrades and enhancements since then.

This paper will discuss the human interface needs for this application, the functional characteristics of the expert system, the development environment and a case history of maintenance on a chiller.

INTRODUCTION

Expert systems for diagnostics are beginning to emerge in the maintenance arena. Operational diagnostics have been discussed [Brothers etal 1989, Culp 1988 and 1989, Haberl etal 1989, Klima 1989 and Anderson etal 1989]. One real time diagnostic system has also been reported [Kaler 1990]. This paper will report on Mentor, an expert system developed to assist mechanics in the preventative maintenance and diagnostics of centrifugal chillers.

Mentor™ was originally released in 1986. Since then, the system has been upgraded and extended to include a larger number of chiller types. The run time software environment was originally an interpreted Lisp (LISt Processing). This has been upgraded to allow larger knowledge bases and to execute the code faster. Mentor is in use in the United States, Australia, Canada and Europe.

A language called Preventative Maintenance Language (PML) was developed to allow application orientated types of people to codify the knowledge of the experts. A example of PML code is shown in Figure 1. The PML code was then converted to LISP and run in an interpretive mode. The original system was very slow. Both the run time environment and the development environment have been substantially upgraded since the system was originally released.

On the run time side, software was developed to convert the PML code directly to C code. The C code was then compiled with an available compiler and vastly improved the run time speed. Another problem which was encountered as the knowledge bases began to outgrow the available memory, which was a DOS based 640K PC compatible. This has been solved by developing a new overlay type of run time environment, called StarFish™, which replaces the original C run time code which did not allow overlays. Very large knowledge bases can now be run since sections of the code are overlaid in memory. The speed is only slightly reduced from the non-overlay C executable code and is still quite acceptable.

The development process originally involved coding PML with an editor and then compiling. In 1987, a graphical development environment, called KlamShell™, was made available which ran on a Symbolics Lisp computer with a cost in the $50K range. KlamShell allowed the knowledge engineer (KE) to view and code the knowledge base graphically. A sample knowledge base (KB) is shown in Figure 2. The KE could easily maneuver through the KB by "clicking" on an action. Modifications or new entries could then be made with all of the syntatax automatically taken care of. The primary constraints were that large KB's were still somewhat awkward with this system and the cost of the development platform was high. To solve this, KlamShell was subsequently ported to a Mac II. This brought down the cost of the development platform by a factor of 5. New features were added which allowed the KE to work with large KB's.

Today, these types of expert systems are developed by interviewing the expert(s), codifying the knowledge using the Mac version of KlamShell, iterively reviewing with the expert until it is complete, creating a StarFish run time file and executing the KB in a laptop PC. A field test then occurs where user information can be verified with the expert(s). It typically takes about one year to go through the entire cycle and have a KB that the mechanic can comfortably use.

END USER SYSTEM FEATURES

One of the main constraints which this effort faced was to present an easy to use interface to the end user, usually a service refrigeration mechanic. These people have intensive mechanical training and skills but have typically had little or no exposure to computers. Also, they are not typists.

The mechanical design was done to minimize the problems associated with low light levels and often no table to put the PC on. Although the Mentor PC is a laptop, any IBM™ compatable PC will execute the knowledge base. The PC is carried to the job in an impact resistant case. The PC has a plate which can be mounted on a tripod, so the mechanic can place the PC and tripod in a convenient spot. The PC screen is electroluminescent so a high background light level is not needed. It should be noted that the PC selected is of a 1986 vintage and many advancements have been made since then. Costs are coming down and new technologies such as touch screens are becoming available. These technologies will be considered for enhancing the Mentor offering as they become avaiable.

Another aspect of the design was to make the computer as non-computer like and user friendly as possible. This was accomplished by two strategies. First, certain keys were labeled as functional buttons. For example, the 'E' key was labeled the explaintion key. Whenever the user wants to get additional information, pressing the 'E' key brought it up. This worked well since the user seldom enters text. When text entry was required, like entering a type of noise, the key became a normal letter, like E. The function could be invoke then by pressing ALT-E. Second, the entries were made multiple choice where ever possible. The mechanic is rarely asked to enter text, thus typing errors can be avoided. Typically, a selection in response to the question is made by entering a number.

Before the user can take Mentor to a chiller, the system must be configured. This allows the knowledge base to accommodate different types of machines, for example, different models, temperature ranges for oil and water and when specific maintenance was last done. The knowledge bases are written to require this information to determine when a task must be done. If the oil must be changed yearly on a particular machine, Mentor will bring this up as a task to be done in a session after one year has elapsed from the last oil change. The important feature is that maintenance gets done at the right time and is not accidently forgotten.

A sample entry screen is shown in Figure 3. The top line is called the banner and contains the title, copyright and time of day. The window on the left side of the screen is the procedure window. All questions and entries are done in this window. The right side window is the resource window. It can contain explanations, data on the chiller, current values entered, graphics, a current transcript of the session and information on where the user is in the knowledge base. These are selectable by pressing active keys.

DEVELOPMENT SYSTEM FEATURES

KlamShell is a powerful development environment which allows the KE to enter the expert's knowledge using English and graphically viewing the entered knowledge base. In one window the user can view the entrie decision tree structure and move a cursor to select the section to view in detail. Another window shows this detail and the user then adds, deletes or modifies the contents of specific actions. A very useful technique in working with the expert is to review the entered knowledge at the KlamShell screen. When experts see how easy their input can be entered, expanded or changed, they are more open to providing information. Figure 2 shows a screen layout of a knowledge base.

To enter a question, the KE clicks the mouse to create an ASK-box. The question is then typed in English. A variable is then selected or created to stroe the user's response. If one needs to be created, the KE is prompted for the required information. If the variable was a water pressure, a variable with the appropriate limits would be set up. KS automatically documents the action with the time and date, the name of the author, and a heading describing the action. The KE can select other action types such a TELL-, IF-, SEQUENCE- and others. The KE can access a complete set of Boolean function and arithmetic functions to control the logic flow. The knowledge engineer then grows the system to the point where it is ready to be tested by an expert.

DIAGNOSTIC SESSION

The session which is illustrated shows how effective an expert system can be in performing preventative maintenance and diagnostics. The interaction with the user is given below.

To begin the session, the mechanic loads the knowledge base for the chiller to be worked on and then loads in the disk containing the specific information on that chiller. A session disk is then inserted to be used during the session. This disk contains the maintenance and repair history. The repair and diagnostic history is used during the session and is updated at the end of the session.

A synopsis of this session is given below. The mechanic first enters the outside air values.

Expert System: What is the approximate temperature outside?

Mechanic: 95 (DegF)

Expert System: What is the outside wetbulb temperature?

Mechanic: 81 (DegF)

Expert System: Is the chiller making any unusual noises?

Mechanic: No

Note here that the mechanic could have said yes. The system would then present choices to try to categorize the noises and zero in on a problem area.

Expert System: What is the condenser refrigerant pressure?

Mechanic: 12 (PSI)

Expert System: What is the condenser leaving water temperature?

Mechanic: 100 (DegF)

Expert System: The condenser pressure is normal.

The mechanic is given feedback as the session continues so that it retains an interactive feel. The system compared the values to the Pressure / Temperature tables for R-11 to see if the pressure was reasonable.

This session continued until the system found that the oil pressure was too high.

Expert System: What is the oil pump pressure?

Mechanic: 20 (Lbs)

Expert System: The oil pressure is too high, given the evaporator pressure. Adjust the oil pressure regulating valve.

The mechanic then tried to make the adjustment. It could not lowered enough so the system had the mechanic go on until the right time to fix the oil pump. Excessive foaming was also observed, indicating that refrigerant was getting into the oil.

The next problem found was that the condenser water pressures were high. The strainer was clogged with algae. The condenser water system was cleaned with algaecide and flushed.

After some other routine maintenance, the chiller needed to be pressurized. The mechanic then repaired the oil pump and replaced the grommet which was allowing refrigerant into the oil.

The chiller was then brought back up, the purge was run until the correct refrigerant pressure / temperature was achieved. It was then started and the oil pressure was verified.

The system had the mechanic check for amperage fluxuations in the motor current. A fluxuation was found. First the guide vanes and guide vane linkages were checked and found to be alright. The system then had the mechanic schedule a motor teardown since the rotor or rotor commutator bar was probably the cause.

Next the system asks for a log. And finally:

Expert System: Make sure the purge is in the normal operating mode. Confirm that all control settings are in their normal operating mode.

Expert System: This is the end of this session. A transcript of this session will be recorded for reporting purposes.

In summary, several problems were found. The most serious was the loose commutator on the motor rotor. The rotor was replaced. Finding this early kept the repair cost under $6,000. If this condition had been allowed to continue, the rotor could have eaten into the stator and required a complete motor replacement. When a motor fails, acids, metalic particles and other materials are sent throughout the refrigerant and oil systems. The cost to replace the motor and do the necessary cleaning can be over $25,000. In the worst case, the commutator could put enough metal flakes to wipe out the bearings and ruing the shaft, impeller and housing. This repair can range from $50,000 to over $100,000, depending upon the chiller. Although this is not a common occurrence, it does happen and should be check on a regular basis.

A problem was found with the oil. It was foaming excessively. This could be due to leaking bearing seals. Mentor isolated the problem to the grommet which passes a wire between the motor housing and the first stage of the compressor. Although this grommet takes about 3 hours to replace, catching this problem early can save a costly teardown later.

The last problem was related to dead algae in the condenser water. As the algae dies it causes the strainer to clog up. This system had to have an algaecide treatment, acid clean and flush to get the condenser water system back to proper operating condition.

CONCLUSIONS

Expert systems technology is very appropriate to helping solve some of the problems encountered in operating and maintaining complex mechanical equipment. Properly applied, expert systems can lead the mechanic to do the correct maintenance at the correct time. Our experience to date shows that these systems can be used to reduce the emergency repair costs and down time of centrifugal chillers.

REFERENCES

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ACTION- CHECK-FOR-LOW-OIL-TEMPERATURE

DOCUMENTATION- "Created by XXX at 11:15 7/9/90
               Edited by XXX at 4:36 7/16/90"

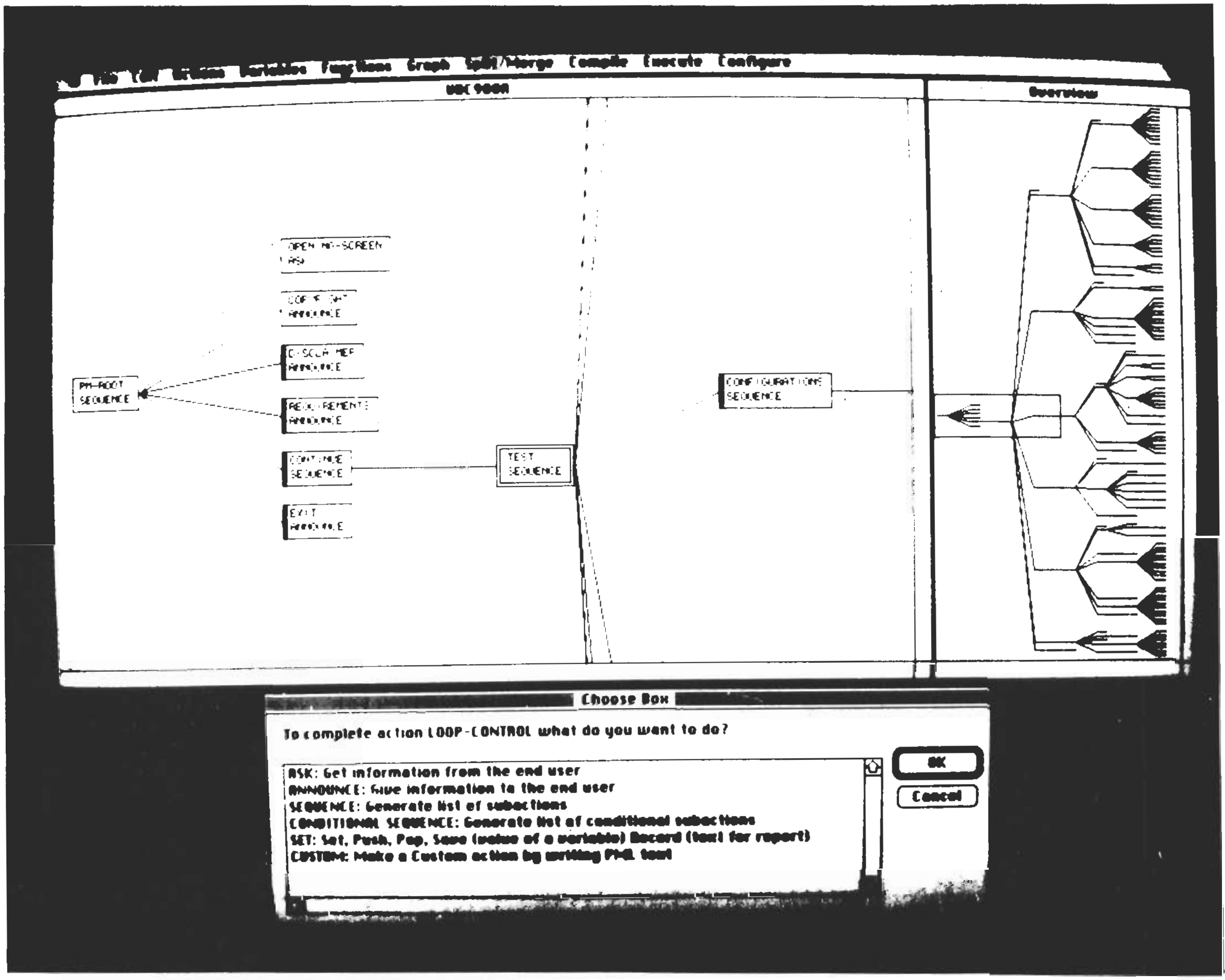
HEADING- "TEST FOR LOW OIL TEMPERATURE

IF- (OIL-TEMPERATURE IS- :LOW)

TELL- (CHECK-HEATER-CIRCUIT
       CHECK-HEATER-ELEMENT)
```

Preventative Maintenance Language (PML) is constructed from simple English-like expressions. The basic programming unit it called an Action, which can contain several types of commands. In the example above, the action is to check why the oil temperature is low. If the oil temperature was not low, the tell clauses of the action would never be executed and control would be passed back to the calling action. In KlamShell the syntax is automatically taken care of. The documentation field is automatically updated when an action is created or modified.

FIGURE 1



This figure is a photograph of a KlamShell screen on the Mac II. The selection across the top of the screen allows the KE to edit, select or add variables, modify the way the screen displays the knowledge base and compile run time code. The diagram in the window on the right side shows a complete layout of the knowledge base and can be used to navigate around the knowledge base. The small rectangular box can be moved around with the mouse and then the larger area on the left hand side will display the details of the knowledge base contained within the rectangle. Each of the boxes in the large window represent an action and they can be modified from this window. The lower window is prompting the user to complete the next action that KlamShell has selected to finish. Various types of actions such as ASK's, Announce's, etc. can be selected.

FIGURE 2

```
MENTOR 3.0 Honeywell Proprietary - One Plaza North          |Units: US|17:19
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PROCEDURE
Make sure the purge is in the normal
operating mode.

Also confirm that all control
settings are left in their normal
position.

Press RETURN when ready.
>
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```
RESOURCE
          -*- MACHINE STATUS -*-

Current Chiller Readings:
Contract............ One Plaza North
Contract number.......... 111-45-984
Serviceman.......................... RM
Model................. CARRIER-19DH
Date...................... 8/7/1990
Condenser pressure....... 12    PSIG
Condenser refrigerant
 temp.................. 130    DegF
Condenser leaving water
 temp.................. 100    DegF
Condenser entering
 water temp.............. 92    DegF
Evaporator pressure...... 14.9  InHg
Chilled water leaving
 temp.................... 46    DegF
Chilled water entering
 temp.................... 56    DegF
Net oil pressure......... 20.3  PSIG
Sump oil temp........... 140    DegF
```

The Mentor screen in this figure illustrates what the refrigeration tech view while working on the chiller. The top or banner line has the name, type of units and time of day. The units can be changed from US to MKS, United Kingdom (UK) or Standard International (SI). The interaction with the user is done through the Procedure window and in this example Mentor is telling the refrigeration tech to check the purge. The resource window is displaying the machine status values which reflect the latest entries.

FIGURE 3