# CHAPTER 4

# EXPERT SYSTEM DESIGN AND DEVELOPMENT

## 4.1 System Design

To design an expert system for diagnosis motor vibration, the existing diagnosis method by human expert is analyzed before implementing with the expert system.

### 4.1.1 Existing Approach



Vibration signal diagnosis is a part of maintenance program. Technician perform their works according to the predefined maintenance plan. Their supervisor assigns daily work to the technician. The technician then go to the field with check sheet. The procedure of each maintenance task is different to each other. According to the maintenance plan, tasks depends on priority of the machine, period of maintenance, physical status of the machine, and so forth.

While technicians go on fieldwork with their check sheet, they collect the data in check sheet for each machine and then go back to the office. Before report the data to the their supervisor, who is supposed to be an human expert, they have to fill all the required data in check sheet. The data will then be interpreted by human expert. The diagram of vibration data collection and diagnosis is shown in figure 4.1.

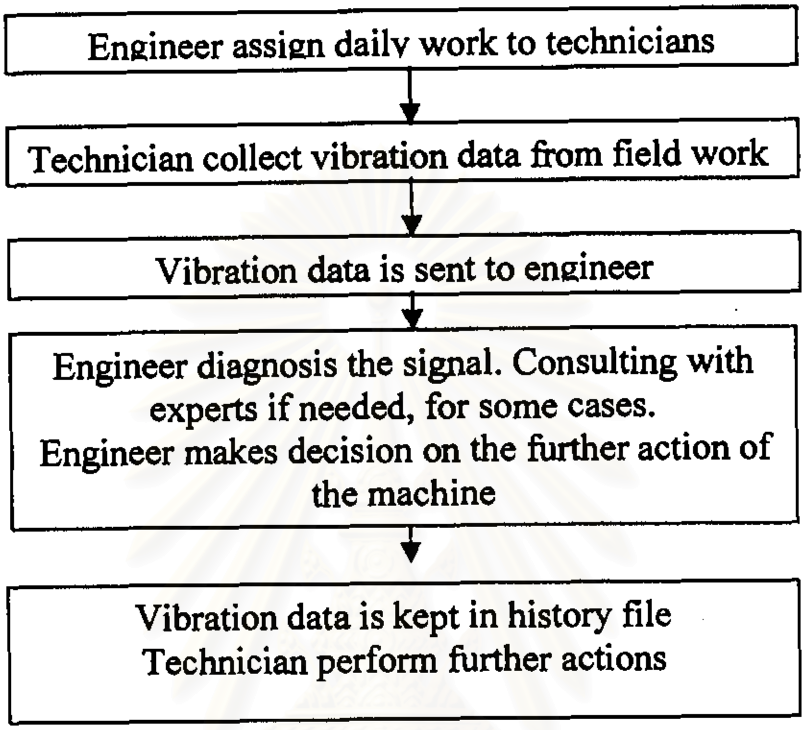



**Figure 4.1** Steps of vibration signal collection and diagnosis

The steps of consulting expert is selected for developing an expert system. The developed expert system should be capable of telling the possible symptom of vibration signal by asking the end user with a set of questions. Then, it should provide the conclusion, including recommendation.



To design the expert system, the steps that human expert should be analyzed and modeled. From the interviewing and consulting, each human expert use different step of analysis: some can give only the final conclusion while some explain their procedures in steps.

The different in diagnosis does not come only from the step of approaching the source of vibration signal, but also from the maintenance policy. For example, some good manufacturing plants may have a good working standard and good maintenance policy. They try to develop their own condition monitoring system in their plant. High efficient tools are provided enough for maintenance work. Therefore, technicians will have enough tools, including the expensive frequency analyzers, for analysis machine's failure.

On the other hands, some manufacturing plants does not have a policy to provide high cost tools, such as frequency analyzer. They only have a basic portable vibration collector. The vibration collector collect the overall vibration signal in time domain. It can not classify peak by frequencies. As a result, only time domain vibration signal can be analyzed.

Therefore, the expert system has to provide both time domain analysis and frequency domain analysis. The ESMVD give both of two ways of analysis.

Since the diagnosis for machine failure is the objective of the system, the ESMVD employ backward chaining as the reasoning strategy. The agenda or assumption of failure is set ranged by the frequent of occurrence.

## 4.2 Design Procedures

The design procedures can be seen in figure 4.2

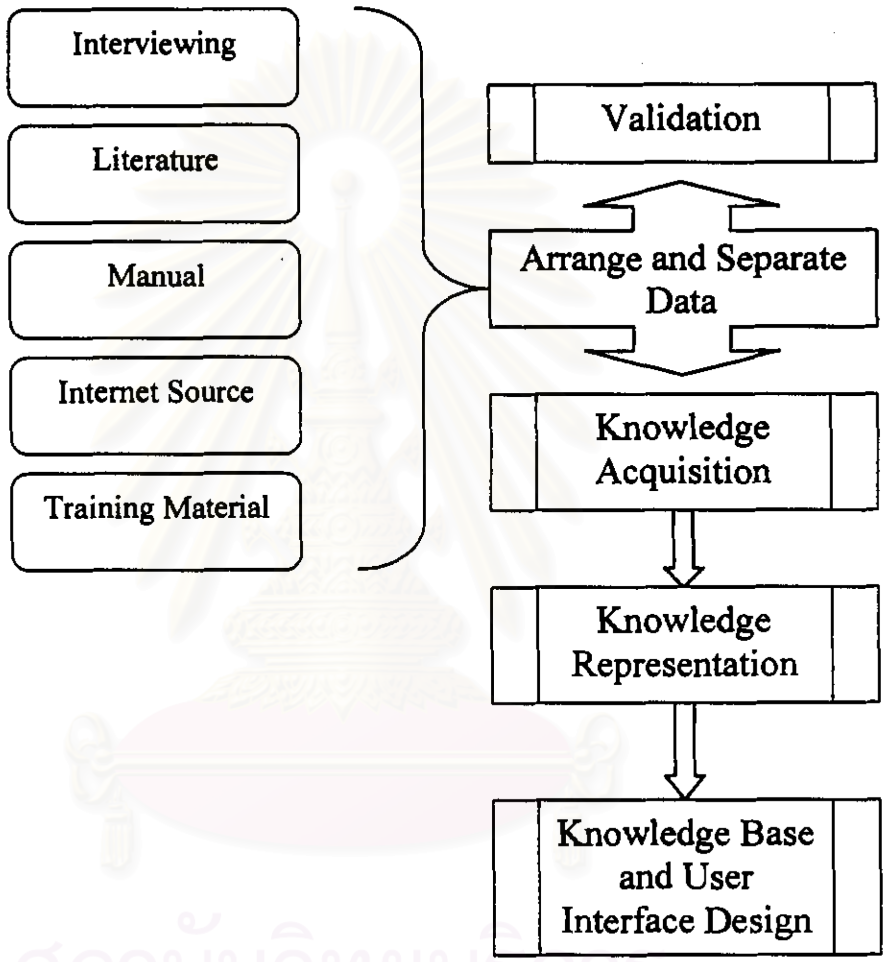



**Figure 4.2** Design Procedures of the ESMVD

In designing the ESMVD, data is collected from various sources as shown in figure 4.2. Collected data has to be arranged and separate into two groups: one group for building knowledge base while the other group is used in validation. Please note that the validation will be done in the last step.

In the separation process, the collected data is separate for knowledge acquisition and validation with the approximately ratio 70/30, respectively. Since the sources to acquire data are limited, especially case study from human experts, building knowledge base has to gain higher priority than validation of the expert system. However, it does not mean that building knowledge base always gain higher priority. If the amount of data is larger, weighing 50% or higher to validation of the expert system could be done.

Building knowledge base starts from knowledge acquisition step. Then, the data will be represented before encoding to the knowledge base. After that, the mechanism of the expert system will be design altogether with the user interface. The detail in each step can be seen in the following section.

## 4.3 Knowledge Acquisition

To acquire knowledge, several methods can be employed. Hence, various sources of knowledge are used as follows:

### 4.3.1 Interviewing

The first step in interviewing process is selecting the human experts. The human experts have to be specialist in machine maintenance field. They have to be familiar with the vibration analysis. Moreover, the manufacturing plant that human expert working with have to have large number of motor providing case studies for knowledge acquisition and validation.

Therefore, two large-size manufacturing plants are selected. They are pulp paper manufacturer and cement plant. Both plants can be classified into large size of manufacturing plant since they have large number of motors. Due to the workload of responsible engineers in both two plants, the interviewing in working time is inconvenient. So, the interviewing has to be conducted informally after working hour.

Since the interviewing is conducted informally, the company profile of both plants should not be shown. However, for background information, the process characteristic is roughly discussed as below.

In paper plant, AC induction motors are used in facility process, such as water plant, which is the plant that supply water to the main process. The main process need high precision of speed control. Hence DC motors are mostly used.

On the contrary, cement manufacturing plant does not require high precision, except in some main processes, such as Kiln, the rotating oven used for baking clinker. So, AC induction motor is the major type of driving machine in cement manufacturing plant.

#### 4.3.1.1 Expected Result from Interviewing

Human expert is the most important domain expert since they can answer and explain interactively in specific question. Therefore, the interviewing process should be done to gain as much as knowledge from human expert. The expected results from interviewing are shown as below.

1. approaching procedures to the problem
2. knowledge from past experience
3. case studies: both historical cases and present cases
4. further explanation in other knowledge sources: human expert should explain or give comment in unclear explanation in other knowledge sources.

#### 4.3.1.2 Interviewing Procedures

The human experts have to be interviewed in four major steps. At each step, they may be interviewed more than one times depending on their availability. The four steps are shown in figure 4.3.

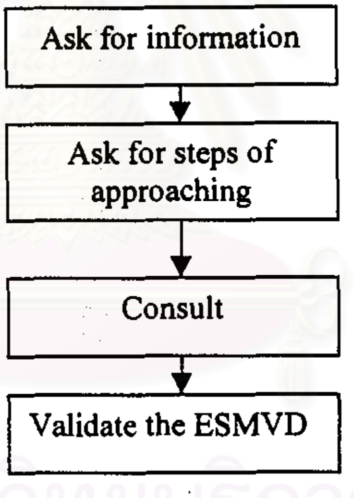



**Figure 4.3** Steps of interviewing

First step is asking for information. Related documents, such as manual of vibration data collector, training documents, training video tape, historical case studies, books, and forth, can be obtained from human experts. Since human experts have been working in vibration analysis for several years, they have collected many sources of data with themselves. At least, they can point out where the sources can be obtained. In this research, most of the sources were obtained from human experts.

After obtaining the sources, studying in detail of those sources have to be done. So, the interviewer will have required basic knowledge in vibration analysis. Next step is asking for the steps of approaching to the problem.

In diagnosis problem, the human experts use their past experience altogether with machine's historical record. In the other words, they just watch the vibration data and then order their technicians for further taking action. The task of interviewer is carving their diagnosis process into steps of approaching.

In doing so, the human experts are not allowed to see the machines' vibration data. They have to ask or to be asked some questions until they can point out the machine's status and possible failure symptom. The example of conversation between human expert and technician in diagnosis the failure of machine from spectrum analysis is shown in figure 4.4. Please note that the meaning of technical terms are provided in appendix D.

- **Human Expert:** " Does the spectrum have dominant peak?"
- ***Technician:*** *"Yes, there is a dominant peak in the spectrum."*
- **Human Expert:** "What is the frequency of dominant peak?"
- ***Technician:*** *"100 Hz"*
- **Human Expert:** "100 Hz is twice of line frequency pointing out to the potential failure of motor."
- **Human Expert:** "Is there any side band around the 100 Hz?"
- ***Technician:*** *"There is not any side band around the 100 Hz."*
- **Human Expert:** "The motor may have stator problem. It should be stopped and bring to workshop for internal inspection"

**Figure 4.4** an example of interactive conversation between human expert and interviewer

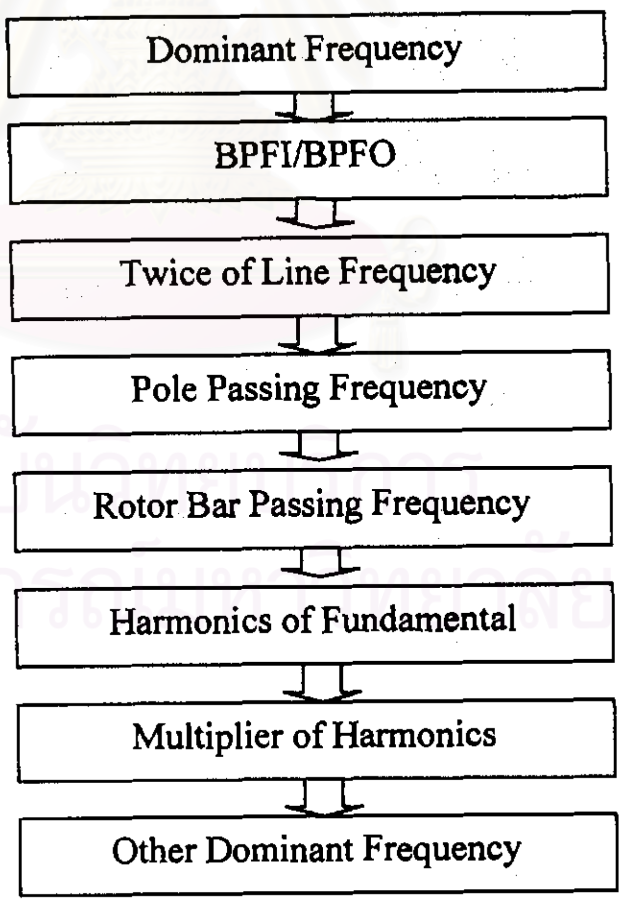
The last two steps of interviewing human experts are consulting and validating the ESMVD. The interviewer will consult human expert when he does not understand some topic in vibration analysis. For example, the interviewer may consult human expert in unclear content in the training document. Another example is when some conflict between two sources of domain expert are found.

After building the prototype of the ESMVD, the validation of the system is needed. The human experts will be asked for cooperation in validation. They were asked to follow up the present case study in for validation in their plant.

#### 4.3.1.3 Steps of Approaching

From interviewing human experts, different steps of approaching the problem are used since they have used different equipment in vibration analysis. The human expert from cement manufacturing plant uses overall value to diagnosis the failure of motors while the human expert from paper plant use frequency analyzer in finding the source of vibration signal.

In cement plant, the guideline to diagnosis the failure of machine is taken from SKF's vibration diagnosis guide [29], which will be discussed in next section. Whilst, from interviewing, the human expert from paper plant use steps of approaching as in figure 4.5




**<u>Figure 4.5</u>** Steps of Approaching in Spectrum Analysis

Please note that the meaning of BPFI, BPFO, and other technical terms can be seen from bearing frequency in Appendix D.

The human expert will ask for 'dominant frequency' in the first step. If there is dominant frequency, then the human expert will ask further questions, which are not shown in figure 4.5. Next, the human expert will investigate the bearing failure frequencies (BPFI/BPFO). If the bearing failure frequencies are shown, he will focus on bearing failure and ask further questions. But if there is not BPFI or BPFO, the human expert will come into internal defect by investigating twice of line frequency. He will eliminate each suspected source, step by step, until the source of vibration is found or none of suspected source could be fired. The detail of each symptom will be discussed in knowledge representation section.

In figure 4.5, the steps of approaching to the failure symptom is just the set of major steps sorting by frequent of occurrence. The detail at each step will be more complex and different in each human expert. However, as far as the experience of human expert covers, the major steps can be used in sorting goals of the ESMVD in the agenda editor. .



**4.3.2 Related Literatures**

The related literatures include books, Thesis, and ISO standard. The books give basic knowledge in vibration analysis and methodology in diagnosis failure of machines. The thesis tells about the past work in vibration field. They were already discussed in literature review in Chapter2.

The knowledge base of the ESMVD use table B1 of ISO 10816-1 as shown in figure 2.1 in diagnosis the failure from overall value.

### 4.3.3 Related Manual Documents

Mostly, the documents available in plants is user manual of vibration tools. The training document from the manufacturer of vibration tools are used altogether with the manual. In principal, guideline in vibration diagnosis is not much different in each brand.

In this research, related document and user manuals are taken from SKF, the bearing and vibration analyzer manufacturer. They are shown as below.

1. Picolog's user manual
2. Microlog's user manual
3. Vibration Diagnosis Guide [21]

The Picolog is SKF's overall value analyzer. It can give only the numerical data. Whilst, the Microlog is SKF's frequency analyzer. Those two equipment's manuals give the detail in measuring the signal while the vibration guide provides the basic knowledge in vibration analysis. Moreover, the techniques and guideline in vibration analysis are given.

The knowledge that used in the ESMVD's knowledge base are concluded from the vibration Diagnosis Guide and shown in table 4.1.

| | Excessive Horizontal | Excessive Vertical | Excessive Axial | *Notes* |
|---|---|---|---|---|
| **Imbalance** | Yes | No | No | *Horizontal > Axial* |
| **Misalignment** | No | Yes | Yes | *Axial > Horizontal* |
| **Looseness** | Yes | Yes | No | *Vertical => Horizontal* |

**Table 4.1** Vibration Diagnostic Table for Horizontal Shaft

(Source: Vibration Diagnosis Guide [21])

The table 4.1 is used for motor that has horizontal shaft. It can roughly point out the possible three symptoms of failure: imbalance, misalignment, and looseness. The word 'yes' means the overall value is excessive. According to table B1 of ISO 10816-1, the excessive level is either the unsatisfactory or the unacceptable level. In the same way, the word 'no' means the overall value is not excessive, or the overall value is in either the good or satisfactory level, according to table B1 of ISO 10816-1.

Likewise, motors with another shaft mounting, the overhung shaft and the vertical shaft, can refer to the value in tables 4.2, and 4.3.

| | Excessive Horizontal | Excessive Vertical | Excessive Axial | *Notes* |
|---|---|---|---|---|
| **Imbalance** | Yes | No | Yes | *Hor & Axial > Vert* |
| **Misalignment** | Yes | No | Yes | *Hor & Axial > Vert* |
| **Looseness** | Yes | Yes | No | *Vertical => Horizontal* |

<u>**Table 4.2**</u> Vibration Diagnostic Table for Overhung Shaft

(Source: Vibration Diagnosis Guide [21])

| | Excessive Radial 1 | Excessive Radial 2 | Excessive Axial | *Notes* |
|---|---|---|---|---|
| **Imbalance** | Yes | No | No | *Radial > Axial* |
| **Misalignment** | Yes | No | No | *Axial > Radial* |
| **Looseness** | Yes | No | No | |

<u>**Table 4.3**</u> Vibration Diagnostic Table for Vertical Shaft

(Source: Vibration Diagnosis Guide [21])



### 4.3.4 Internet Source

Both official and unofficial web sites on today's internet can be used as another source of vibration knowledge base. Most of those sites provide cases as their successive work. They also provide onsite analysis of vibration signal. However, the data on web have to be screened before adding it to knowledge base since it does not be documented as interrogation paper. The example of internet data taken from

Stevens' homepage [27] are shown in the figure 4.6 and figure 4.7. There are the case of bearing defect and lubrication deficiency.

The information contained for this example is shown as follow.

*"Rolling element bearings are among the most important components in the vast majority of machines and exacting demands are made upon their carrying capacity and reliability. The continued research and development of rolling bearing technology has enabled engineers to calculate the life of a bearing with some considerable accuracy, thus enabling bearing life and machine service life to be accurately matched. Unfortunately it sometimes happens that a bearing does not attain its calculated rating life. There are many reasons for this - heavier loading than had been anticipated,* ***Inadequate or unsuitable lubrication,*** *careless handling, ineffective sealing or fits that are too tight with resultant insufficient internal bearing clearances. Each of these factors produces its own particular type of damage and leaves its own special imprint on the bearing. This case history serves to demonstrates the possibility to detect in some cases the effect of inadequate lubrication within a rolling element bearing. The machine used for this demonstration is a 2 speed 1475/990 rpm/90 hp cooling tower fan motor. during testing of the motor it was observed that an intermittent high pitched noise was being omitted from what was suspected as the NDE bearing. Overhaul velocity rms. readings throughout the motor exhibited values below 1 mm/sec rms and were considered low and acceptable. To determine the cause of this noise, a set of 5000Hz acceleration readings were obtained from both the NDE and DE motor bearings in the vertical, horizontal and axial directions. On examination of the spectra from both DE and NDE bearings in the vertical direction a 'haystack' effect was evident in the region of 2000 to 3500 Hz"*

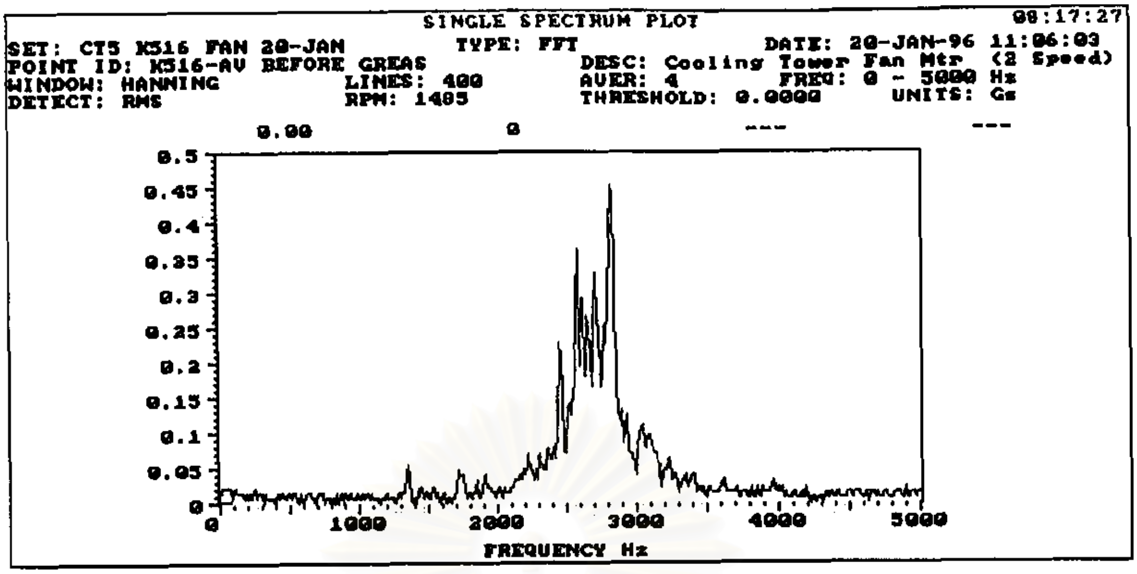



**Figure 4.6** Spectrum of bearing lubricant deficiency

Source: Steven's homepage [27]

From figure 4.6, Steven gives an explanation as follow.

*"Vibration Spectrum Before Lubrication: this type of spectrum, based on experience, is normally generated by a reduction in the lubrication effect resulting in some degree of metal to metal contact within the rolling element bearing. If this condition is not remedied then accelerated bearing wear will occur leading to an increase in operating temperature and consequent bearing failure.*

*Once the condition had been determined, it was decided to apply a given amount of lubricating grease to this bearing. With the vibration data collector set to analyser we were able to monitor the immediate effect the lubricating grease had on the vibration. After grease was added and distributed within the bearing the live spectra indicated a slight recurrence of the original condition, it was then decided to apply a further few shots of grease. The effect was immediately noticeable with a considerable reduction in vibration activity exhibited by the analyser. The same procedure was carried out at the motor DE bearing, see vibration spectrum below."*

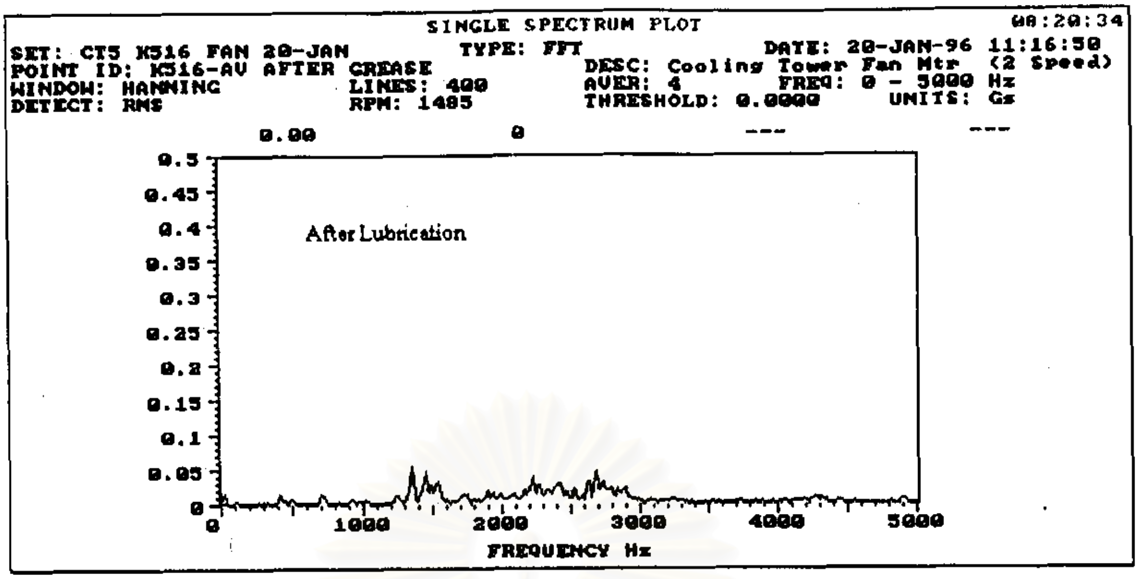



**Figure 4.7** Spectrum after greased

Source: Steven's homepage [27]

### 4.3.5 Other Training Source

Apart from documented paper and Internet sources, other type of source can be used in knowledge acquisition, including videotape. The advance vibration analysis part 1 and part 2 is the training videotape teaching basic concept in vibration measurement and guideline in diagnosis internal failure within the AC induction motor. The videotape is made by Coastal Video Communication Corporation in 1996 [9] The content inside covers rotor problem and stator problem, including problem from power supply.

## 4.4 Knowledge Representation

After acquire information from various source, the information should be selected, analyzed, and transfer into knowledge form. It should be represented in the form that easy for encoding into knowledge base.

There are many ways to represent knowledge. The fundamental production rule is the most popular form in expert system field. In the Level5 Object, such a presentation form have to link with the object structure. So, presentation of object structure of the ESMVD should be done first. The basic structure is shown in figure 4.8.

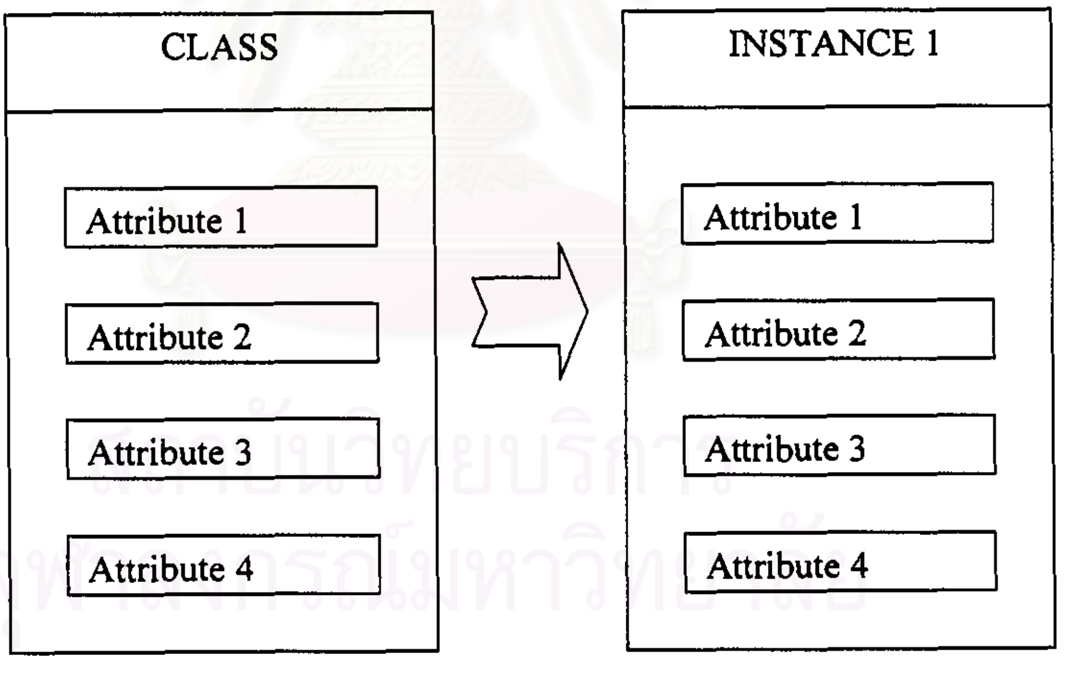



**Figure 4.8** Object Structure in the Level5 Object.

From figure 4.8, An object's structure is defined by its class and attribute declarations. The class may have no attribute or many attributes depend on designing. Instance is subclass of the class. It has the same attribute to the class. Also, class may have no instance or many instances. Figure 4.9 present an example of object structure in the Level5 Object.

**CLASS:** radial spectrum

(s) RPM1X

(s) RPM2X

(s) Harmonics

(s) subharmonics multiples

(s) sporadic harmonics

**Figure 4.9** An example of the object structure.



From figure 4.9, the class 'radial spectrum' is shown. It has three attributes. All of them is simple attribute. The more detail of object's structure can be found at online manual at ruelsmachine web site [19].

The knowledge base will refer to the attribute of the class. An example of rules in the ESMVD is shown in figure 4.10.

IF motor has coupling
AND there exists 1X running speed OF radial spectrum
AND there exists 2X running speed OF radial spectrum
AND amplitude of 2X is greater than 50% of amplitude of 1X
OR there exists 2X running speed of radial spectrum without accompanying of any harmonics
THEN Misalignment

**Figure 4.10** rules for misalignment symptom

According to figure 4.10, the condition in the IF-THEN statement is written in human-readable language. However, when encode into knowledge, the conditions have to be slightly changed for conciseness in rule programming. Although the language is not pure human language, it can be guess and understand.

The knowledge rules for misalignment of the ESMVD are shown in figure 4.11, figure 4.12, and figure 4.13.

IF live OF coupling
AND ((RPM1X OF radial spectrum
AND RPM2X OF radial spectrum)
OR (RPM1X OF axial spectrum AND RPM2X OF axial spectrum))
THEN misalignment OF spectrum symptom

**Figure 4.11** Rule for misalignment with confident factor 100

IF live OF coupling

AND RPM1X OF radial spectrum

AND RPM2X OF radial spectrum

AND RPM2X greater than 100% RPM1X OF amplitude

THEN misalignment CF85 OF spectrum symptom

**Figure 4.11** Rule for misalignment with confident factor 85

IF live OF coupling

AND RPM1X OF radial spectrum

AND RPM2X OF radial spectrum

AND RPM2X greater than 50% RPM1X OF amplitude

OR (RPM2X OF radial spectrum

AND NOT harmonics OF radial spectrum)

THEN misalignment CF70 OF spectrum symptom CF 70

**Figure 4.13** Rule for misalignment with confident factor 70

The reason that misalignment uses three rules instead of one long rule is each rule has different confident factor. On the other word, the ESMVD has different confidentialness in pointing out the failure symptom in different conditions.

For all rules in the ESMVD's knowledge base, please see in Appendices: Appendix A for overall value and Appendix B for vibration spectrum. For the explanation of the symptom, please see in appendix C.

## 4.5 ESMVD Structure

There are many expert shells can be used in developing the expert system. The Level5 Object is one of the most popular expert shells. It was developed by Information Builders [11] until release 3.6. Then, Rule Machines Corporation (www.rulemachines.com) took over the right in the Level5 Object.

The Level5 Object has many advantage points as below.

It support Graphic User Interface

It support both audio and video file

It support SQL format

Its session monitor is very helpful when debugging the application.

It provides many useful objects, which is very helpful in developing application

Etc.



With the many advantage points, the ESMVD was developed on the Level5 Object, the expert shell for expert system development. After the acquired knowledge was analyzed and represented, it is encoded to ruled base. (The rules based can be seen in Appendix A and B.) Then, the user interface can be designed and created.

Fortunately, the Level5 Object has many functions that support friendly user interface, such as push button, pulled down menu, imported bit map file, and forth.

The ESMVD structure has 3 main panels; the measurement comment, the overall value analysis, and the spectrum analysis. The picture of three main panels is shown for clearly understand in figure 4.14.

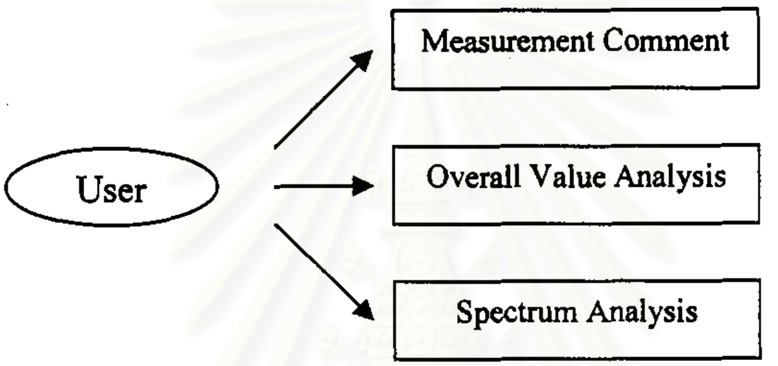
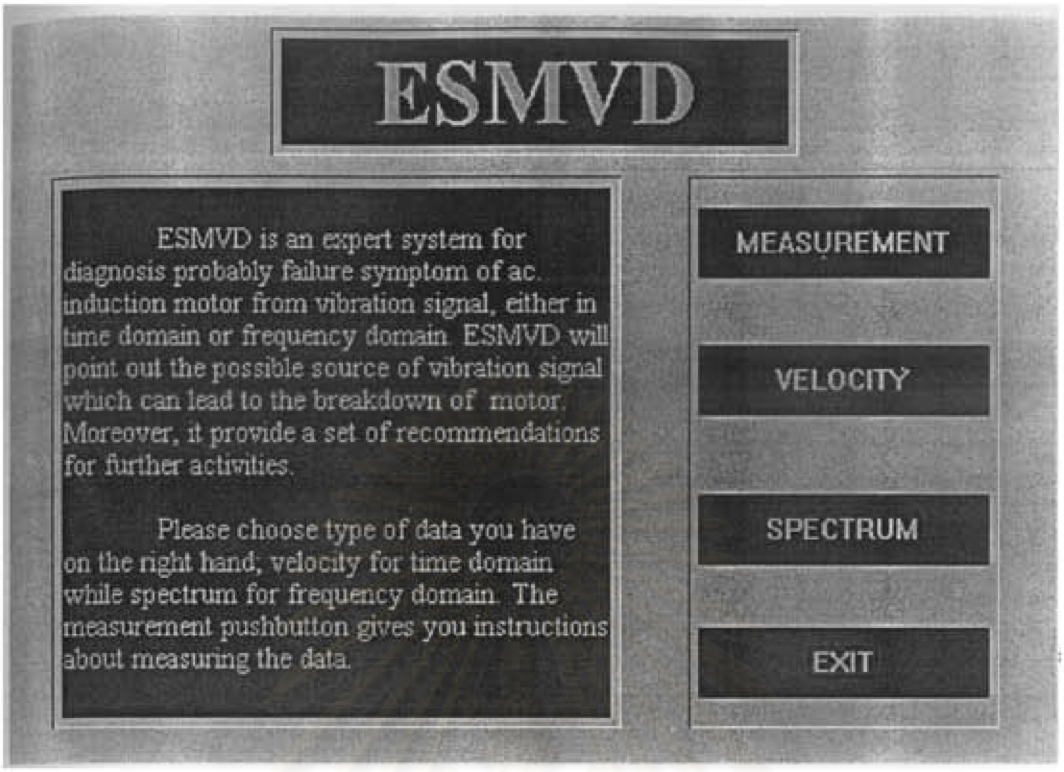



**Figure 4.14** Three main panels of the ESMVD

User can start expert system, ESMVD, by starting the Level5 Object first. Then, select open/run from the menu bar. Next, open the file esmvd.knb. The introduction display will appear firstly as show in figure 4.15.




<u>**Figure 4.15**</u> Introduction display of ESMVD

**4.5.1 Measurement Recommendations**

The display give information about the expert system, ESMVD. User can select what techniques used for diagnosis vibration signal from the push buttons in the right. The MEASUREMENT push button can be selected to explore about the measurement information. The last push button, EXIT, is for exiting the program.

The MEASUREMENT display provides the information about measuring techniques for the reliable information. It can be seen as below.

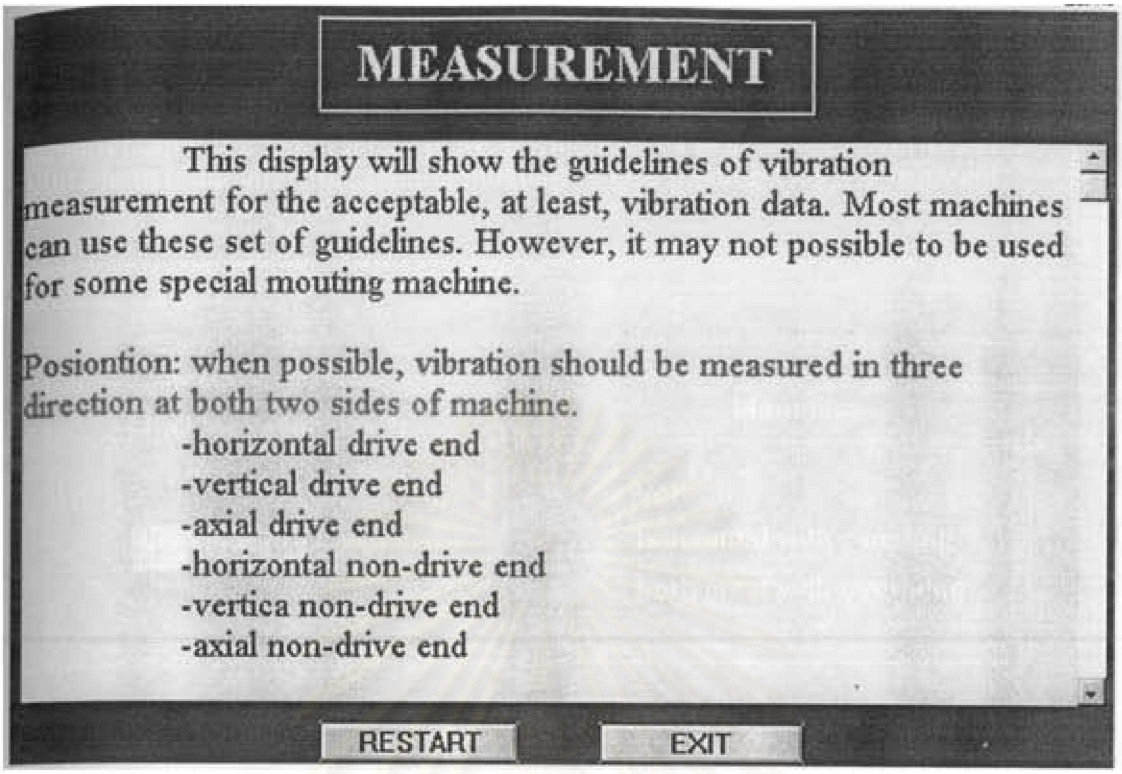



**Figure 4.16** Measurement display of ESMVD

ESMVD give an opportunity for user to select either the time domain technique or frequency domain technique. In most manufacturing plants, the tool used for collecting the vibration signal are portable vibration probe. However, for some manufacturing plant, the higher price-frequency analyzer is used.



### 4.5.2 Diagnosis on Time Domain

When user select the velocity puss button, ESMVD will ask for the primary data of the machine; rated power and type of mounting as shown below.

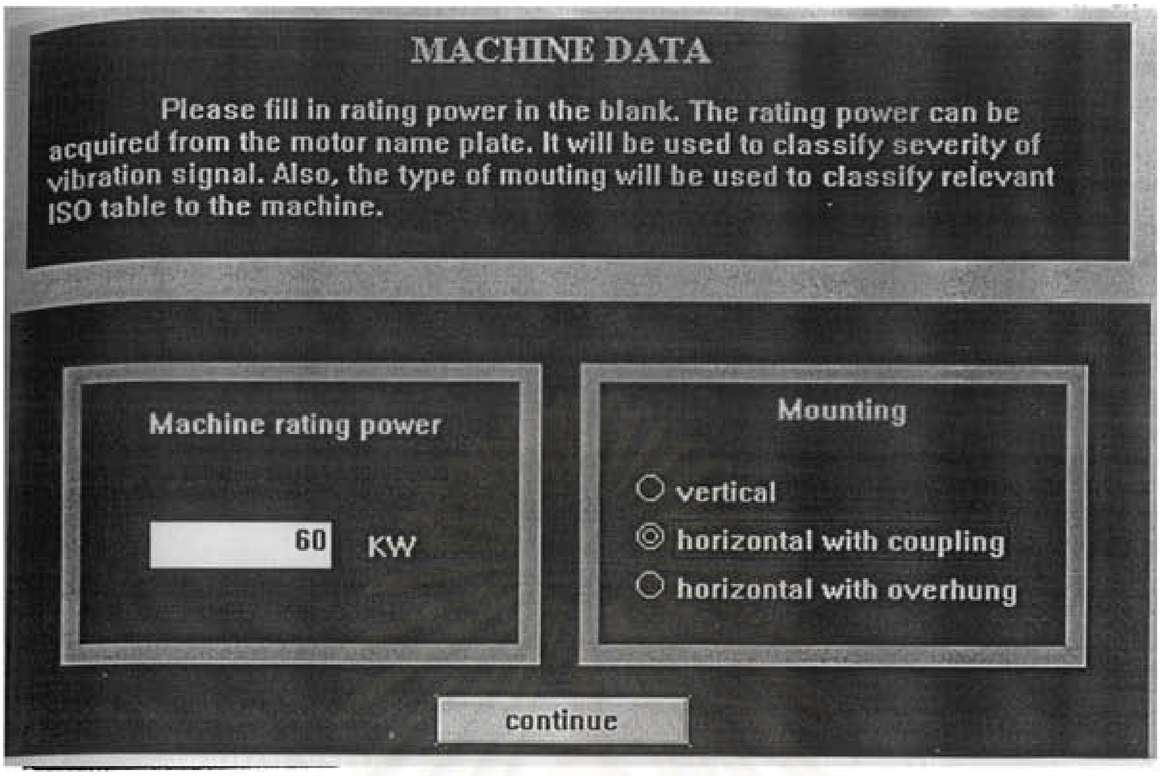



**Figure 4.17** Inquiry display of ESMVD on time domain

The user has to fill all the required value. If the rated power is out of range (10 – 1,000 kW), the error message will be shown as in figure 4.5



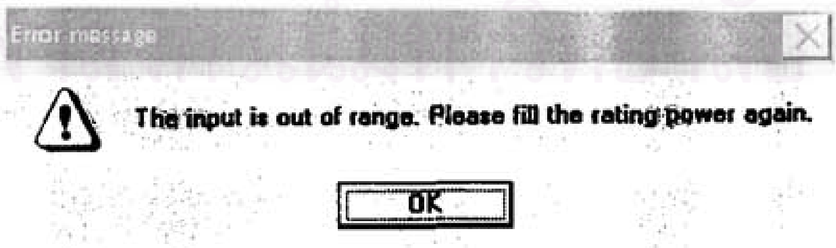
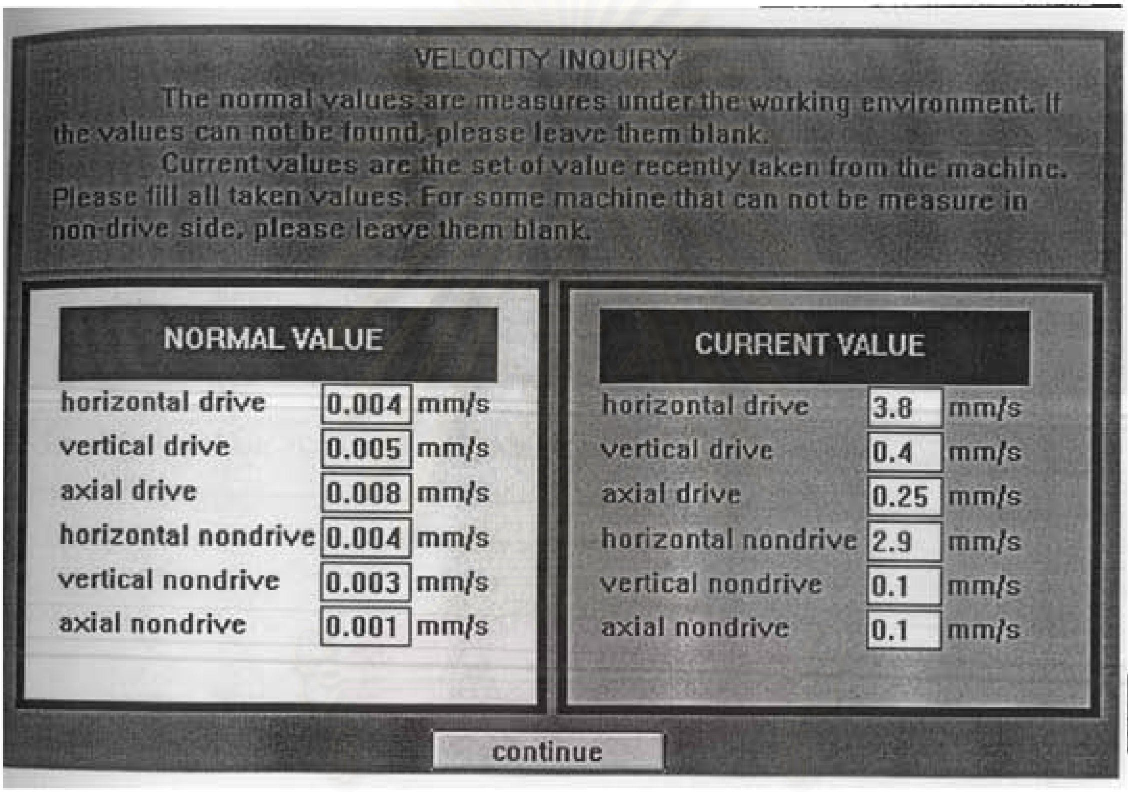



**Figure 4.18** Error message of ESMVD

After filling all the data and click continue. The user will be asked again for vibration value. The top screen is the explanation about the required data for the user. The normal blank on the left-hand side is for primary offset data of each machine. On the right-hand side, the required current value of velocity is shown in figure 4.19.




**<u>Figure 4.19</u>** Velocity inquiry display



The filled value will be calculated for the machine's status. The ESMVD will give the current status in the machine status screen. With the color function of the Level5 Object, the level of severity can be shown in different colors.

-green for good

-blue for satisfactory

-yellow for unsatisfactory

-red for unacceptable

The status of machine is shown in all three plane of measurement. The lower screen shows the explanation of machine status as show in figure 4.20.

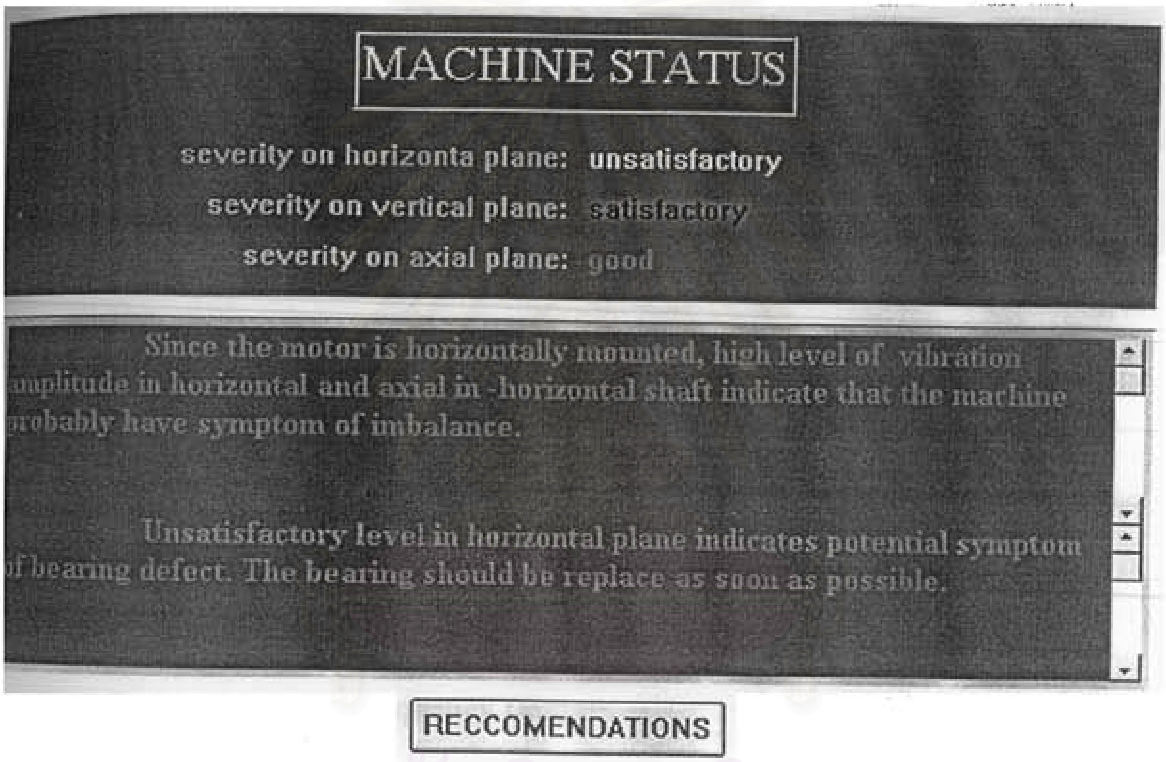



**Figure 4.20** Machine status



Next screen gives the recommendation for the user. If the machine is o.k., the recommendation can be show as in figure 4.21.


**Figure 4.21** Recommendation for the machine

Until this step, the user is given an opportunity to select restarting the application or exit the application.

### 4.5.3 Diagnosis on Frequency Domain

Unlike time domain, the spectrum analysis uses an interactive display to communicate with the user. The ESMVD start with simple questions depending on what agendas are ranged. The machine data screen in figure 4.22 asks the user to fill some information about frequency. Then those information will be calculated and represented as the probable failure frequency of the machine as shown in figure 4.10. Figure 4.11 is the interactive display.

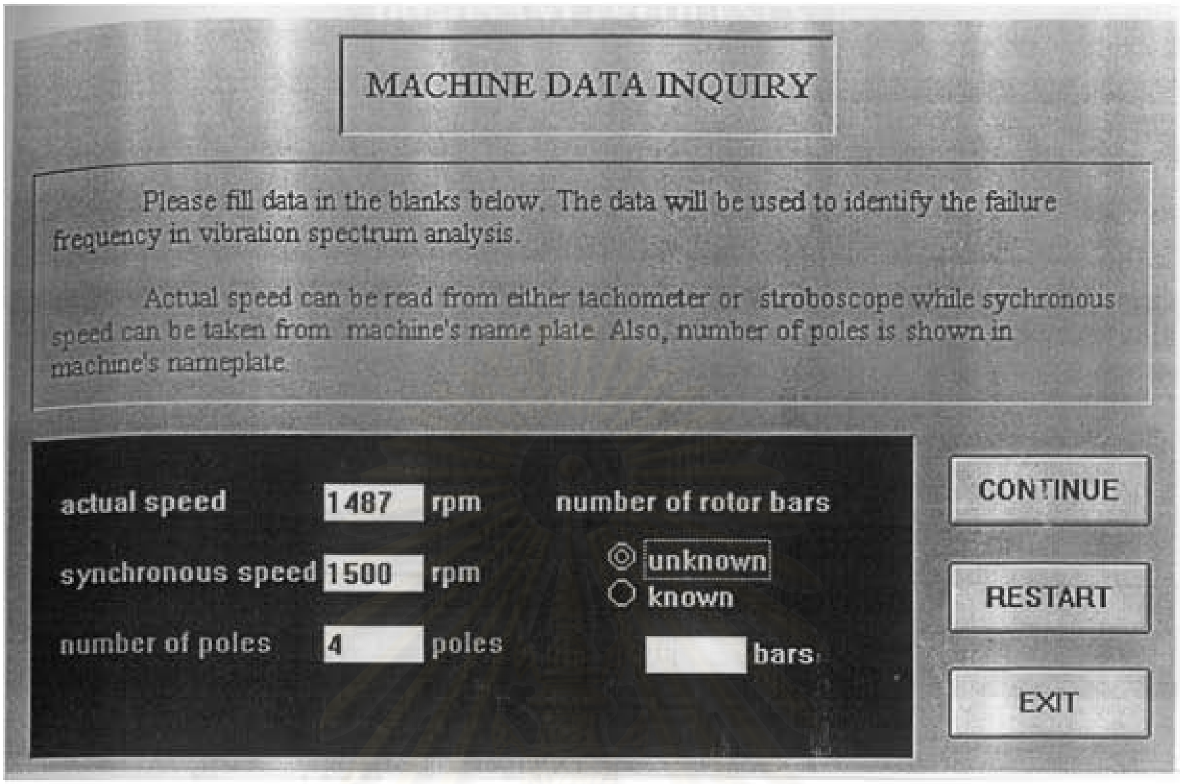



**Figure 4.22** Machine data screen

The data in this screen will be calculated and then display dominant failure frequencies that may be the source of vibration. Figure 4.23 shows the screen of dominant failure frequencies.

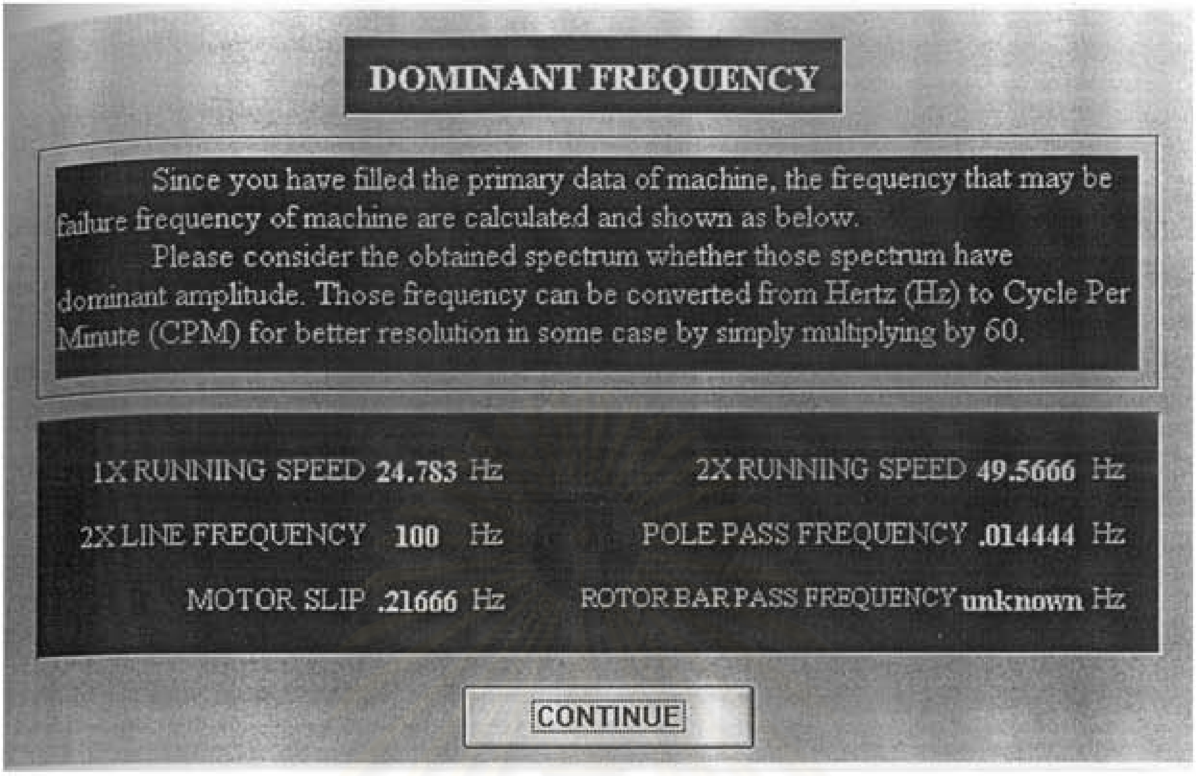



**Figure 4.23** Dominant Failure Frequencies

The user can notice in the vibration spectrum for failure frequency from screen as in figure 4.23. After that, the user will be asked by series of questions in interactive display as show in figure 4.24.

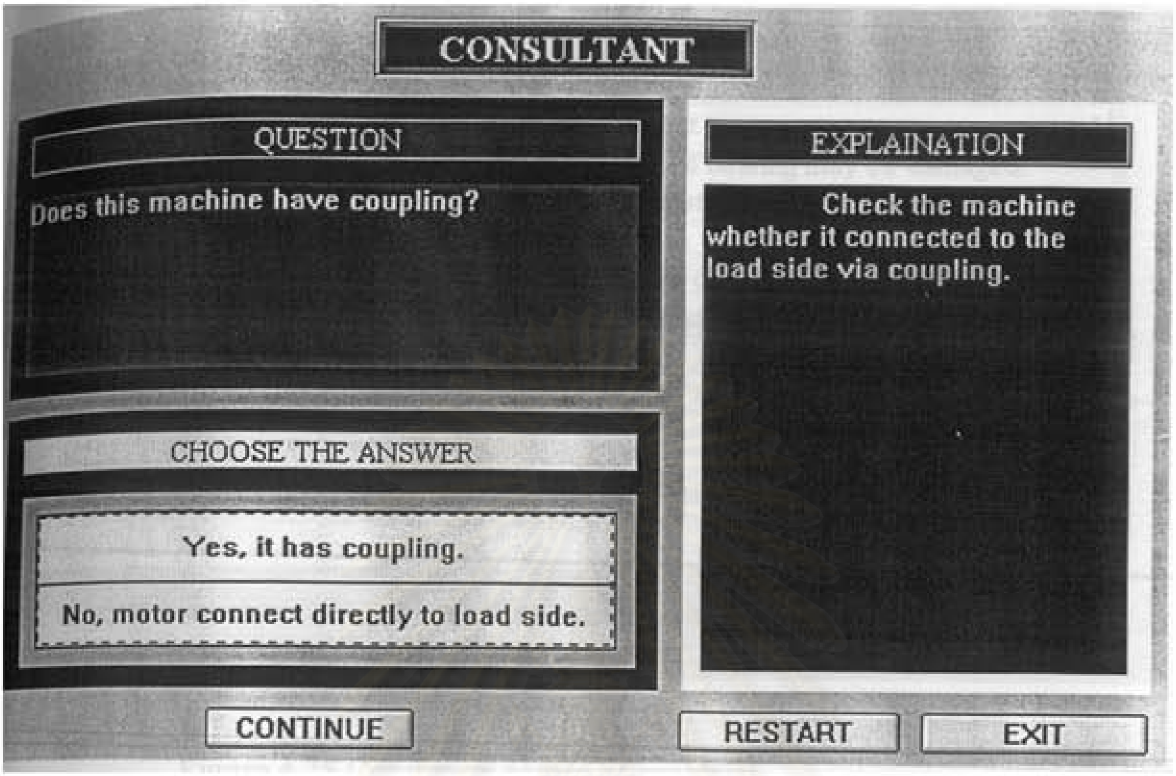



**Figure 4.24** Interactive display in spectrum analysis

The consult display will ask the series of questions to scope down the possible source of vibration spectrum. User just selects yes or no answer in the answer box. The right side of the screen is the recommendation for each question. When the conclusion is reached, the conclusion screen for spectrum will is shown in figure 4.25

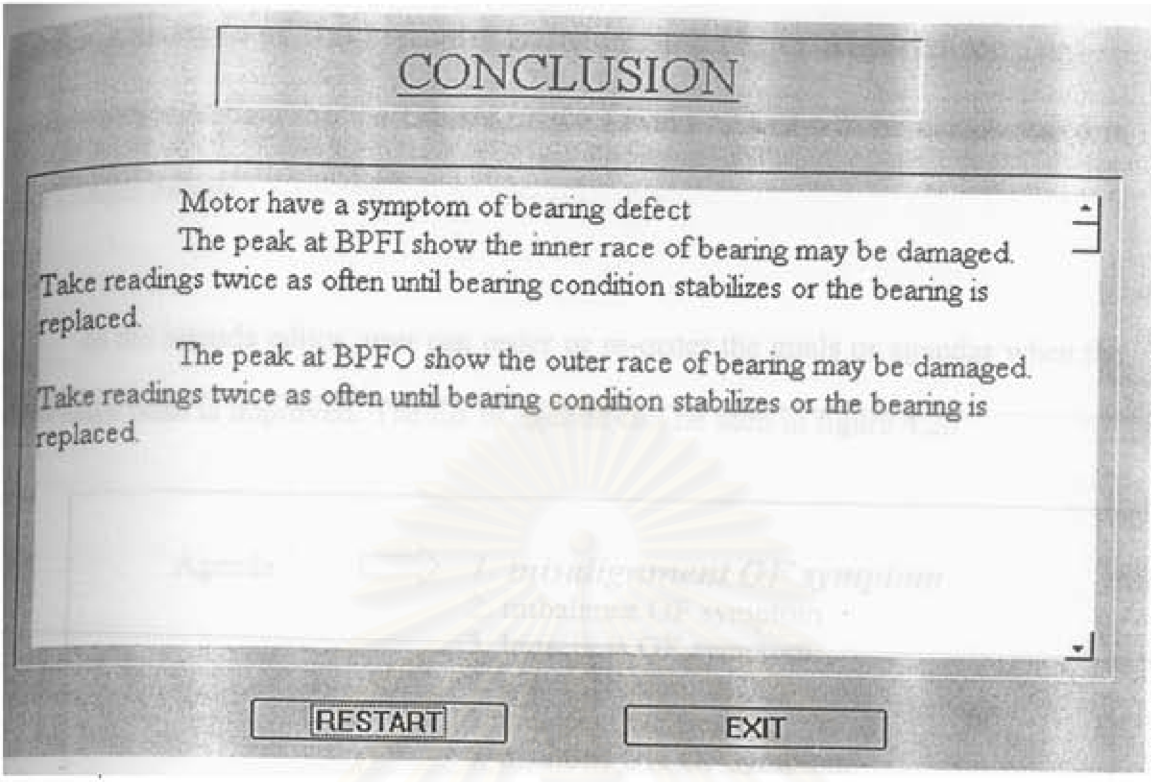



**Figure 4.25** Conclusion screen of spectrum

As far as the knowledge base knows, the application can make a conclusion to the user. In case of unknown spectrum is shown, the ESMVD will assume that the signal may come from load side, which is beyond the scope of ESMVD. Then the user has to consult human expert again. However, the user can update the new knowledge base after the human expert can find the conclusion.

## 4.6 An Example of Backward Chaining Searching Algorithm

In this section, the mechanism of the Level5 Object will be demonstrated in the example below.

In the agenda editor, user can order or re-order the goals or agendas when the knowledge base is improved. The list of agenda can be seen in figure 4.26

Agenda ⇨ ***1. misalignment OF symptom***
2. imbalance OF symptom
3. looseness OF symptom
4. unsat OF bearing
5. unaccept OF bearing
6. machine OK OF symptom
7. misalignment OF spectrum symptom
8. misalignment CF 85 OF spectrum symptom
9. misalignment CF 70 OF spectrum symptom
⇨ ***10. soft foot OF spectrum symptom***
11. imbalance CF70 OF spectrum symptom
12. imbalance CF60 OF spectrum symptom
13. imbalance CF50 OF spectrum symptom
14. looseness CF85 OF spectrum symptom
15. looseness CF50 OF spectrum symptom
16. bearing defect OF spectrum symptom
17. inner race defect OF spectrum symptom
18. outer race defect OF spectrum symptom
19. rotor rub CF70 OF spectrum symptom
20. rotor rub CF60 OF spectrum symptom
21. coupling CF75 OF spectrum symptom
22. coupling CF75 OF spectrum symptom
23. coupling CF75 OF spectrum symptom
24. coupling CF75 OF spectrum symptom
25. rotor problem OF spectrum symptom
26. eccentric stator OF spectrum symptom
27. SCR fault CF85 OF spectrum symptom
28. SCR fault CF80 OF spectrum symptom

Figure 4.26 Agenda list of the ESMVD

The arrows in figure 4.8 point to the starting goal, misalignment OF symptom, and the target agenda, soft foot OF spectrum symptom; in this example, the soft foot OF spectrum has to be proved.

The inference engine starts with the first goal in the knowledge base's agenda, misalignment OF symptom. The rule is processed until it can be fired. For example, at the agenda number 10, soft foot OF spectrum symptom. The inference engine will backchains from the goal, checking its search order to determine the strategy for reaching the goal. The search order of soft foot is shown below.

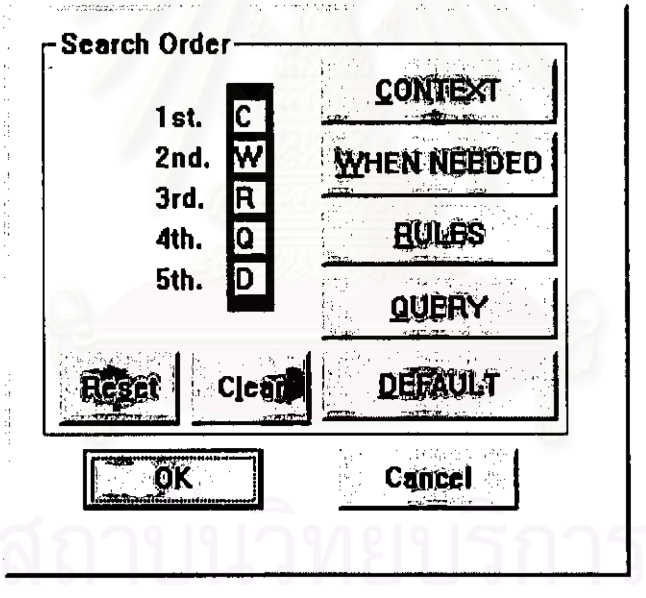



**Figure 4.27** Search Order Editor of Soft Foot Symptom

The search engine will start at session context before go to rules and default. If the inference engine determines from the search order that it needs it evaluate the knowledge base rules, it will pursue all the rules that can determine the goal. The inference engine searches backward to find an antecedent in a rule that supports soft foot OF symptom. It is the rule 310 as shown in figure 4.28

| |
|---|
| RULE 310 soft foot |
| IF RPM1X OF radial spectrum |
| AND RPM2X OF radial spectrum |
| AND RPM1X peak smaller than RPM2X OF horizontal spectrum |
| THEN soft foot OF spectrum symptom |

**Figure 4.28** Rule number 310 of the ESMVD

Since it needs to verify if the applicant's RPM1X OF radial spectrum, RPM2X OF radial spectrum, and RPM1X peak smaller than RPM2X OF horizontal spectrum, the inference engine checks the search order of RPM1X OF radial spectrum first in an attempt to find where it can obtain that information. The search order of RPM1X is context, when needed, rules, query, and default. Then, it searches the value of RPM1X OF radial spectrum and found that it need user query. The 'when needed for RPM1X' will ask user for the value. The interactive display to ask the user as shown in figure 4.29

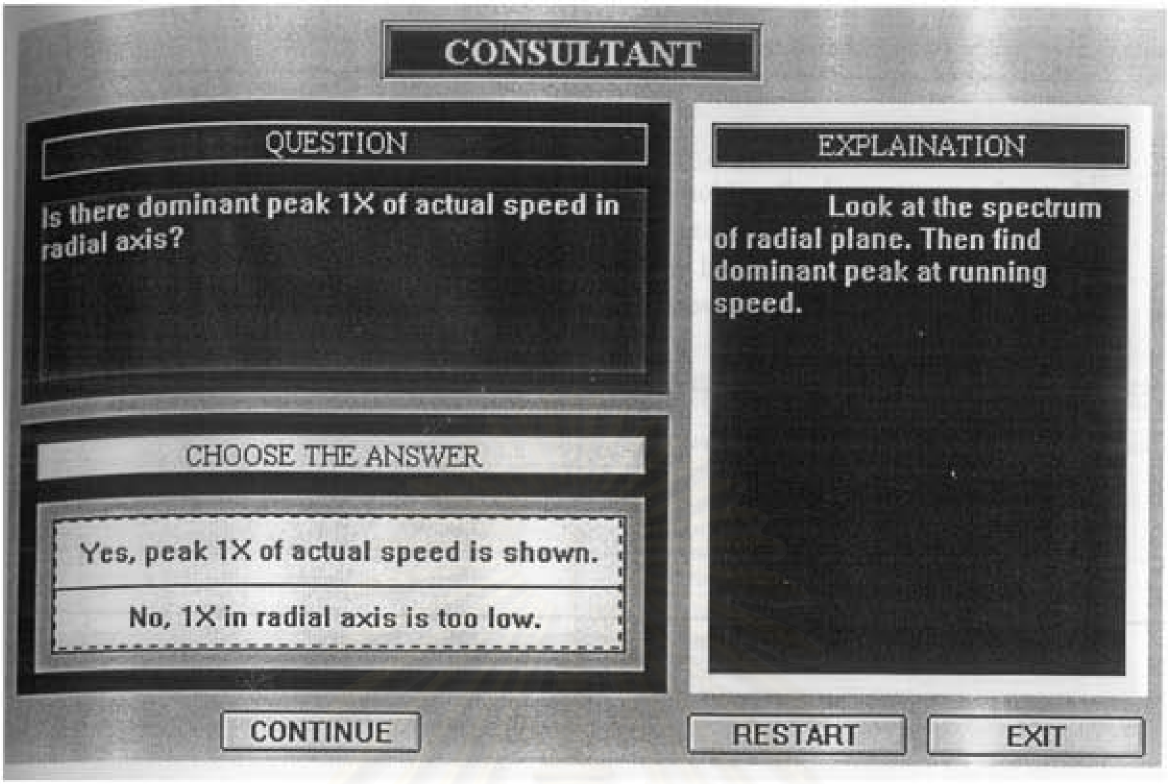
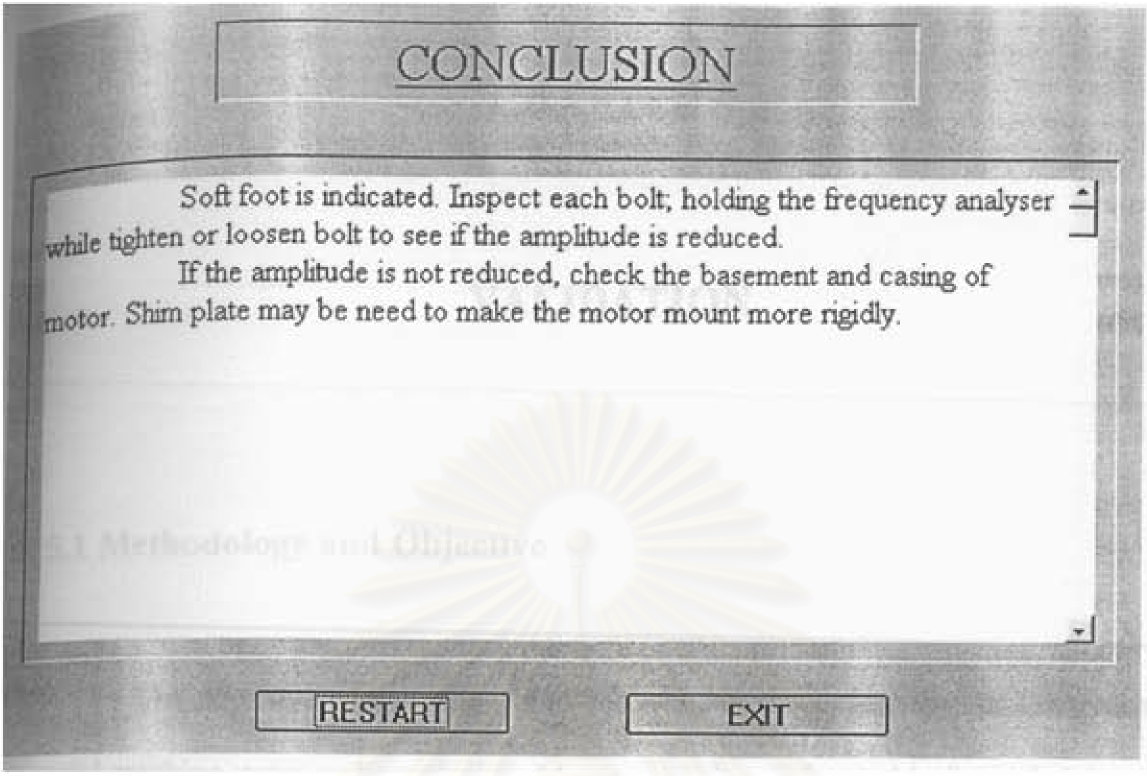



**Figure 4.29** Interactive Screen

The user has to determine from the spectrum whether there is dominant peak 1X of actual speed in radial axis or not. If the user select yes, the value of RPM1X OF radial spectrum will be true. Then the inference engine continue to fire another antecedents.

If all the antecedents are fired, the conclusion that soft foot OF spectrum symptom is true will be made. Until now, we assume that the conclusion is true. Then, the recommendation from ESMVD will be given as shown in figure 4.30.




**<u>Figure 4.30</u> Conclusion Screen**