# CHAPTER 5

# VALIDATION

## 5.1 Methodology and Objective

The objective of validation is to see whether the expert system can give the valid machine status and conclusion. Moreover, it has to be usable for technician. To meet the objective of validation, two technicians were asked for test the data. They have to start the expert system, and then answer or fill relevant data asked by expert system. They have to continue each step by themselves.

The criteria for validation process are presented in figure 5.1. The form will be marked by users who validate software.

| Validation Form for the ESMVD | | |
|---|---|---|
| **Criteria** | **Available** | **Marked** |
| User friendly | 30 | |
| Correctly telling the symptom | 35 | |
| Reliable Recommendations | 35 | |
| **Total** | **100** | |
| **Comment** | | |

**Figure 5.1** Validation Form for the ESMVD

The correctly pointing out to the symptom and the reliable recommendations gain more weighed in scoring because they affect the reliable and effectiveness the expert system. Nevertheless, it does not mean that user interface is not important to the system. If the system has user friendly function, it will be another factor to inspire the user to use the ESMVD and increase effectiveness in implementing the expert system into the real work. While the effectiveness of recommendations and the motor status can be validated by engineer, human expert, or developer, the user-friendly function has to be validated by only the user. Therefore, the validation process should be done by technician who always consults human expert. Nevertheless, it does not convenient for the technician to weigh the score correctly. They just can tell whether the EXMVD is effective and can be used instead of human expert or not. The comments from validation process were done by oral. Therefore, such a form was not used in validation process.

Actually, in validation any computer software, more factors have to be considered, such as developing budget, the security in human experts' work, and forth. Without implementing into the real work, however, such main three criteria are sufficient for validating the ESMVD.

Validation process uses separated data, however, from the same sources as knowledge base. The data is taken from both historical data and new data. The historical data is used to validate the time domain while new data is closed watch to see the final result whether the knowledge base can cope with it. The same source of validation and knowledge acquisition is presented again in figure 5.2

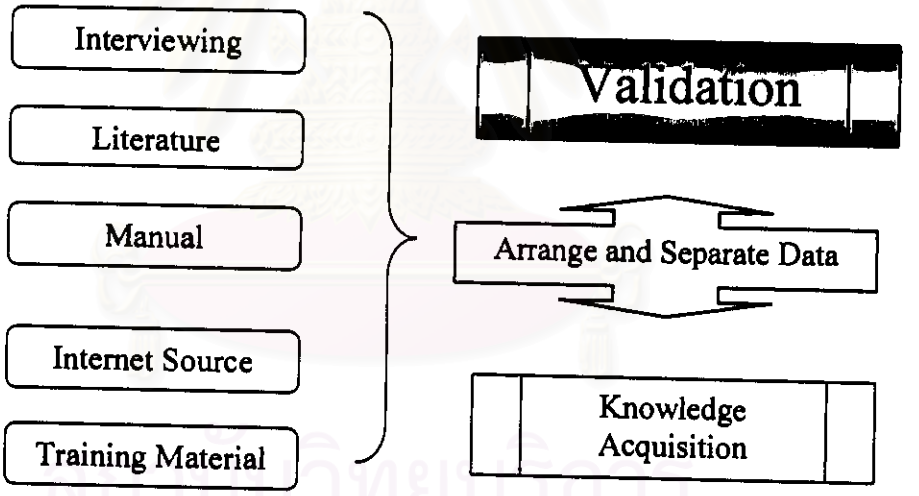


**Figure 5.2** Data for Validation

In addition, in this validation process, the cases, both historical record and present data, are taken from two sources: the cases from human experts and the cases from Internet web site.

### 5.1.1 Validation Procedures

In validation process, technician has to bring vibration data and start the ESMVD by himself. Next, he will be asked for filling machine data and its vibration data. After the ESMVD give the machine status and recommendations, the actual historical record will be compared to the ESMVD's output. In case of present data, the output of ESMVD has to be record and then waiting for comparing to the real situation. Otherwise, the input of ESMVD has to be recorded instead. Then, when the motor breakdown or stop for inspection, the actual status of the motor can be examined and compared to the ESMVD's output again. The process of validation can be seen in figure 5.3.

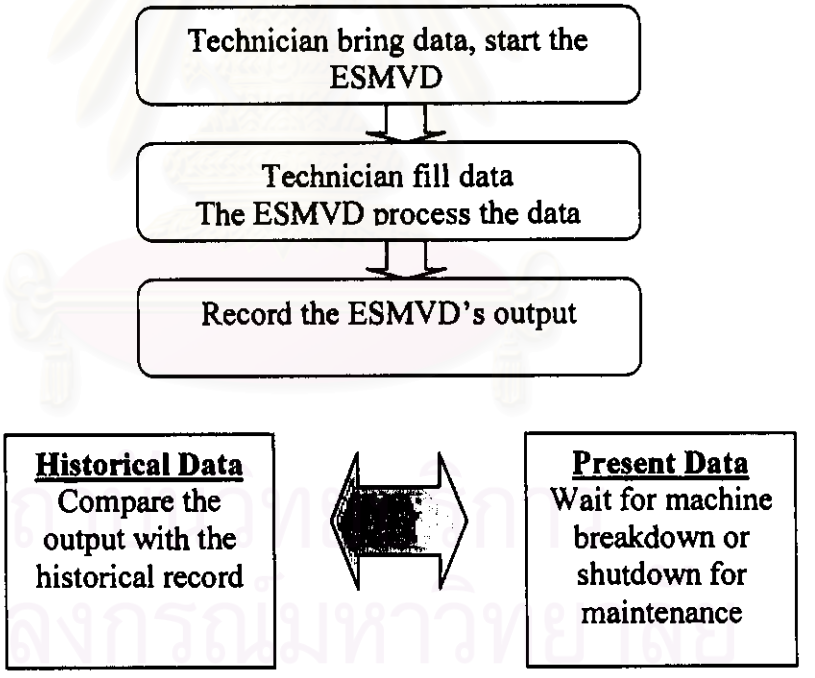


**Figure 5.3** Validation Procedures

## 5.2 Validation Process for Overall Value

The 10 cases of overall vibration signal are used in testing the overall value on time-domain. It comprises of five cases from historical record and 5 cases of present data. The historical data is the data before the motors were diagnosed in the past and the result of machine are already known. On the other hand, present data is the data from the machine that waiting for failure diagnosis; the status and failure symptom are not known yet. So, the result from the expert system have to be proven in the future.

### 5.2.1 an example of overall value

The example of data taken from cement plant for validation process is shown in table 5.1.

| Machine | | Date | Current (A) | | | Vibration (mm/s) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | DE | | | NDE | |
| Code | Description | | R | S | T | V | H | A | V | H |
| 1N1M053 | Sepol Seperator | 22/03/98 | 367 | 369 | 365 | 2.3 | 5.7 | 5.8 | 1.7 | 6.9 |
| | | 21/06/98 | 400 | 400 | 400 | 4.0 | 16.9 | 10.9 | 1.8 | 12.0 |
| | | 28/06/98 | 364 | 364 | 364 | 3.4 | 6.1 | 6.2 | 2.9 | 5.7 |

**Table 5.1** Overall Data for Validation process.

Please note that R, S, and T are symbol of three-phase current. For vibration symbol, V is for the vertical plane, H is for the horizontal plane, and A is for the axial plane.

The motor '1N1M053' is used for driving the Sepol Seperator in Cement Mill Plant. The Sepol Seperator is used for classifying the size of cement dust before send to packing process. The motor itself has rated power at 500 kW. It was installed horizontally with coupling.

At date 22/03/98, machine can be operated normally. The vibration shows normal value

At date 21/06/98, technician found that the vibration value is too high. However, the machine can not be stopped.

At date 28/06/98, technician top up the lubrication of the bearing. The vibration level decreased; however, it is still in the high value.

**5.2.2 the ESMVD's Output**

After starting the ESMVD, technician selected velocity push button. Then, fill in the machine rating power and type of mounting. The velocity value will be required in the inquiry display. Figure 5.4 show the inquiry display of overall value.

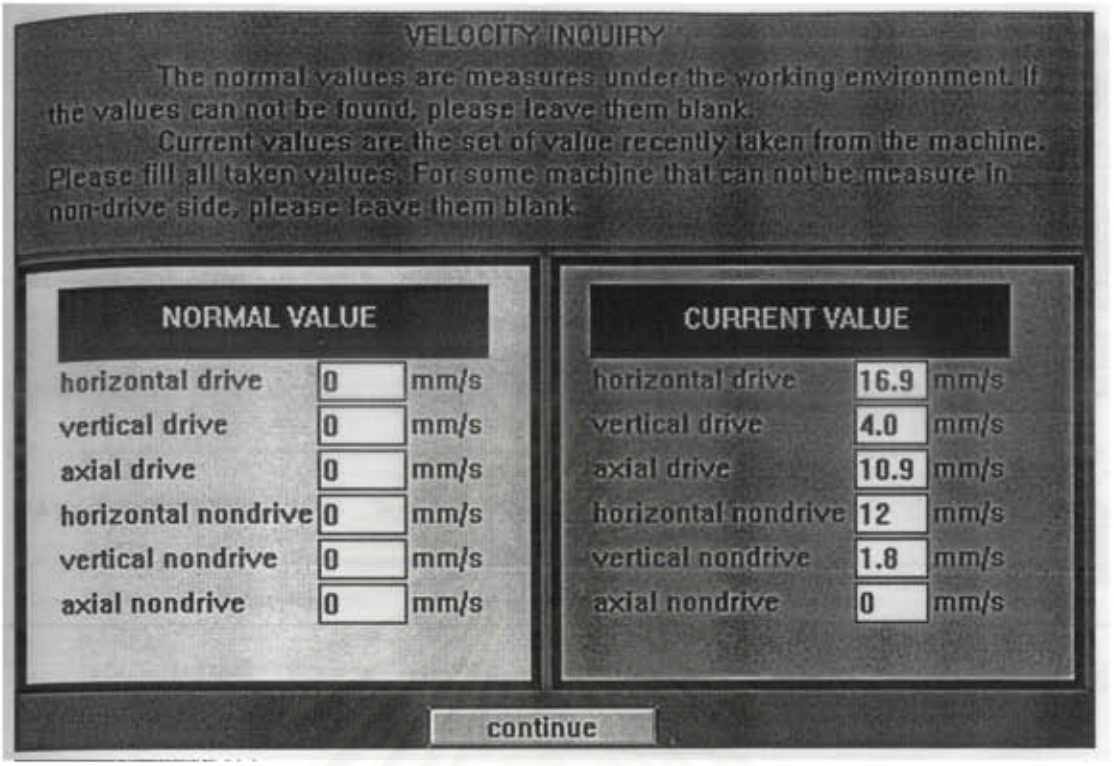


**Figure 5.4** The inquiry display

The normal value is left with zero since it does not appear in historical record. Also, the axial value at non-drive end is left with zero since it can not be measured. Then, the machine status is presented in figure 5.5.

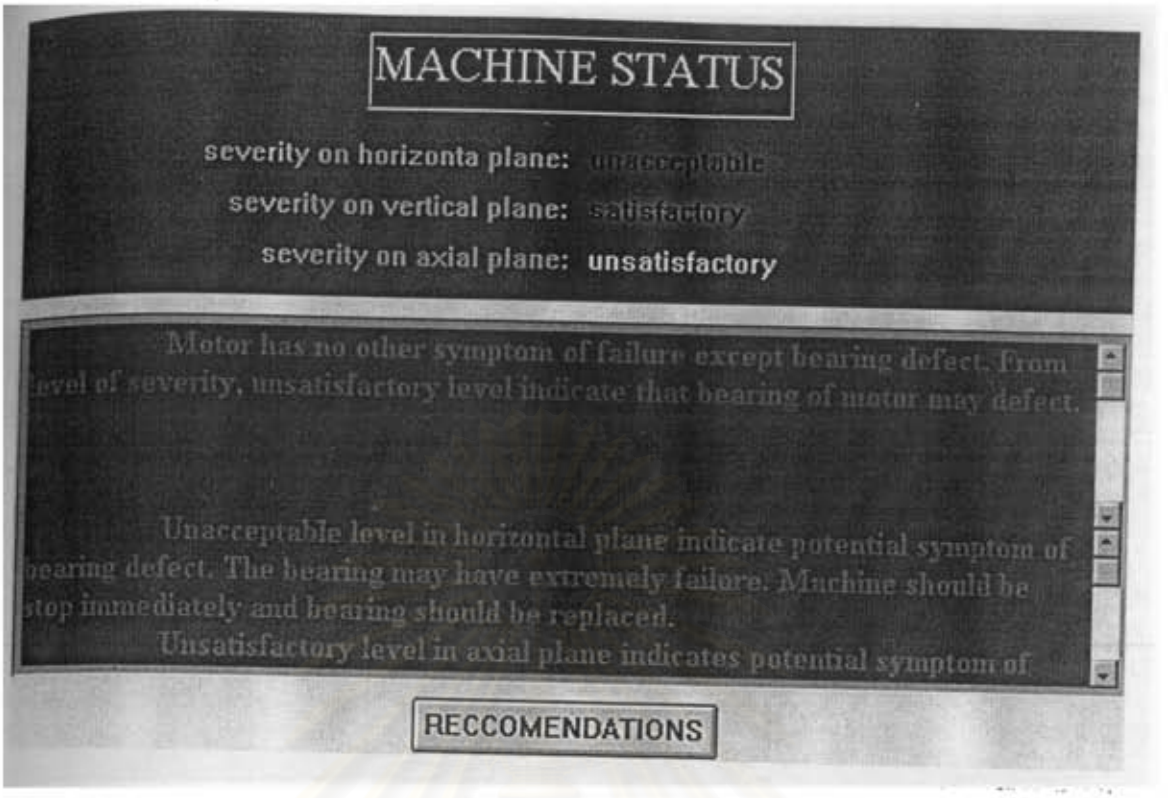


**Figure 5.5** Machine Status

The severity of motor in horizontal plane is unacceptable, showing in red. Whilst, the severity level in vertical and horizontal plane are satisfactory and unsatisfactory, showing in blue and yellow respectively.

ESMVD tell that the motor has only bearing defect symptom. The unacceptable level in horizontal plane help in confirming the bearing defect. Figure 5.6 will show ESMVD's recommendations.

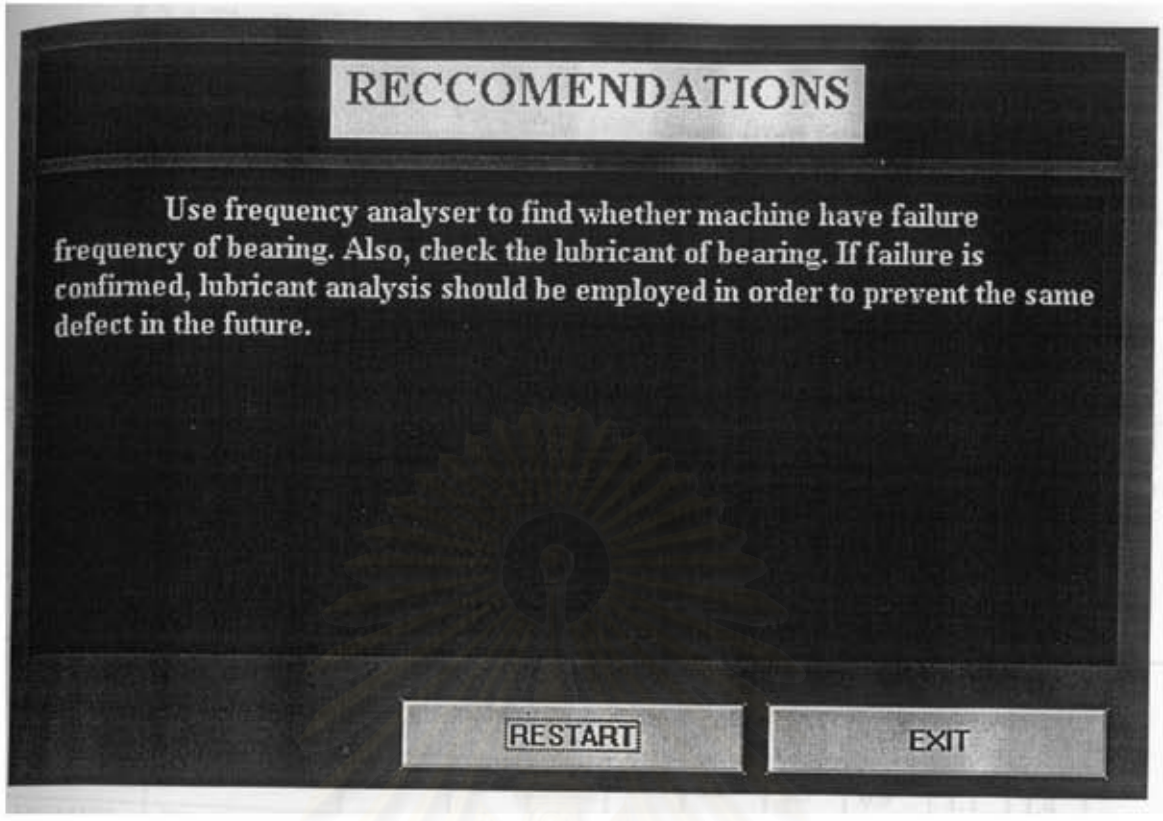


**Figure 5.6** ESMVD's recommendations

The ESMVD recommend technician to use frequency analyzer to confirm the defect. However, the frequency analyzer is not available in cement plant.

### 5.2.3 Comparison between the ESMVD's Output and the Actual Data

The historical actual data is given that the vibration level decrease when lubricant is topped up. It means that vibration signal come from lubricant deficiency. However, the level of severity did not come down to satisfactory level or good level. Such data point out to the defect of bearing. It is the same as what the ESMVD concluded and recommended. Therefore, the validation of the ESMVD in this case is satisfied.

### 5.2.4 The Other Overall Cases

The rest of the cases for validation process are from four historical records and five present values. All ten cases are taken from cement plant. They are show in table 5.2 and table 5.3.

| Machine | | Date Year 1998 | Current (A) | | | Vibration (mm/s) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | DE | | | NDE | |
| Code | Description | | R | S | T | V | H | A | V | H |
| 1N1M178 | Filter Fan | 12/03 | 25.6 | 25.4 | 27.3 | 10.9 | 17.1 | - | 3.7 | 12.3 |
| | | 21/03 | 25.6 | 25.5 | 26.1 | 1.9 | 0.9 | 0.9 | 1.1 | 1.4 |
| 1N1M170 | Filer Fan | 28/06 | 10.3 | 10.4 | 10.5 | 10.3 | 1.2 | 11.3 | 2.9 | 5.7 |
| | | 30/06 | 10.4 | 10.4 | 10.5 | 2.1 | 1.1 | 2.3 | 2.1 | 1.9 |
| 1M1N753 | Compressor | 15/04 | 8.4 | 8.4 | 8.4 | 11.8 | 7.5 | - | 10.2 | 7.1 |
| | | 16/04 | 8.4 | 8.5 | 8.4 | 2.3 | 1.2 | - | 2.2 | 1.5 |
| 1N1M102 | Belt Conveyer | 25/08 | 24.2 | 26.6 | 24.9 | 1.8 | 1.6 | 1.2 | 1.5 | 1.3 |
| | | 26/11 | 25.3 | 26.7 | 25.1 | 1.7 | 1.7 | 0.9 | 1.6 | 1.5 |

**Table 5.2** Historical Record of Overall Value

| Machine | | Date Year | Current (A) | | | Vibration (mm/s) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | DE | | | NDE | |
| Code | Description | 1998 | R | S | T | V | H | A | V | H |
| 1N1M174 | Filter Fan | 12/03 | 25.6 | 25.4 | 27.3 | 10.9 | 12.4 | 18.7 | 10.1 | 10.4 |
| | | 21/06 | 27.2 | 27.0 | 27.4 | 2.0 | 0.9 | 2.0 | 2.1 | 1.4 |
| 1N1M100 | Filter Fan | 28/12 | 36.4 | 36.4 | 36.4 | 2.1 | 0.3 | 1.7 | 2.1 | 2.5 |
| | | | | | | | | | | |
| 1N1M101 | Belt Conveyor | 11/09 | 7.2 | 7.4 | 7.3 | 7.8 | 6.8 | 8.1 | 7.9 | 7.2 |
| | | 30/12 | 7.6 | 7.5 | 7.4 | 1.1 | 1.7 | 2.1 | 1.3 | 1.4 |
| 1N1M229 | Separate Fan | 12/12 | 10.3 | 10.5 | 10.6 | 3.2 | 8.3 | 1.7 | 2.9 | 7.1 |
| | | | | | | | | | | |
| 1M1M305 | Scraper Conveyor | 21/06 | 6.5 | 6.5 | 6.5 | 5.4 | 8.7 | 4.2 | 5.7 | 9.2 |
| | | 21/09 | 6.7 | 6.6 | 6.4 | 1.2 | 2.7 | 1.8 | 1.2 | 1.9 |

**Table 5.3** Present Overall Value

### 5.2.5 Comparison of the Result

In the same validation procedures, the ESMVD's output has to be compared with the actual data. The comparison result can be seen as follows.

#### 5.2.5.1 the ESMVD's output and the result in historical record

With the machine data in historical record, the ESMVD can process and give the conclusion from the vibration data. The comparison result is shown in table 5.4.

| Machine | Actual Result | Conclusion from the ESMVD |
|---|---|---|
| 1N1M178 | After replace bearings at both sides, the velocity values are sharply dropped, as measured while reinstallation. | Bearing is severely damage Unacceptable severity level in all three plane Motor should be stopped immediately |
| 1N1M170 | Topping up lubricant in bearing did not bring down the vibration value. Next, motor is realigned. The vibration value is significantly decreased | Misalignment symptom is shown. Bearing may be defect either from itself or lubricant deficiency Use frequency analyzer or phase detector to confirm the assumption. |
| 1M1N753 | Motor is sent to workshop for inspection. The bearing at drive end is defected. Then, it is replaced by new one. Vibration level decrease after reinstallation. | Bearing is severely defected. The reason may come from bearing itself or from lubricant deficiency. Motor should be stopped immediately. |
| 1N1M102 | Motor is normal. | No failure symptom is shown since motor's vibration values in three planes are satisfactory. Motor can be used However, the bearing may be earlier defect, which can not be detected by overall value regularly. |

**Table 5.4** Comparison between the ESMVD's output and historical records.

**5.2.5.2 the ESMVD's output and the result of present data**

With the same method as historical method, the comparison result is shown in table 5.5

| Machine | Actual result | Conclusion from the ESMVD |
|---|---|---|
| IN1M174 | Motor breakdown. The investigation found outer race of bearing melt with the rolling ball. Breakdown of motor damages the filter in main process. Motor is sent to rebuild and reinstall in three months later due to production plan reason. | Bearing is severely defected. The reason may come from bearing itself or from lubricant deficiency |
| IN1M100 | Motor breakdown from locked rotor due to breakdown locked load. It may come from shocked load or locked bearing at load side. | Motor has no symptom of failure. However, the bearing may be earlier defect, which can not be detected by overall value. |
| IN1M101 | Motor is sent to overhaul. The bearing at the drive end side is replaced. Vibration values, after reinstallation, decreased. | Bearing is severely damaged Unacceptable severity level in all three plane Motor should be stopped immediately |
| IN1M229 | Motor has soft foot condition. One bolt used to fit motor on the floor loosed. After tighten the bolt, the | Motor has symptom of looseness. Use frequency analyzer to scope down possible |

| | | |
|---|---|---|
| | vibration level decreased. | source of looseness. |
| 1M1M305 | Motor has high temperature on its casing. It is inspected and found that connection of power supply line is loosed and nearly melt. It is fixed and tightened.. The vibration values are in good level in no-load test.. However, it is high when test on load. The inspection found that bearing at load side is damaged. | Unacceptable level in both horizontal and axial plane show the symptom of bearing defect. Motor should be stopped and inspected. |

**Table 5.5** comparison between the ESMVD's output and present data

### 5.2.5.3 Result of Comparison

In time domain, ESMVD can give the reliable diagnosis result. It can show the level of severity of machine. For the suspected symptom that provide in the machine status display, It successfully proves with eight cases from both historical record and present data. The possible symptoms of failure, such as misalignment, looseness, were proved altogether with the bearing defect in unsatisfactory or unacceptable level. Whilst, another two cases present the limitation of the ESMVD in overall value analysis.

In case of motor 1N1M100, the small vibration values give cause the ESMVD to give the wrong conclusion: motor is normal. Whilst, the actual present data show that the motor breakdown from locked rotor. The ESMVD can not point to the symptom of failure from load side.

In case of motor 1N1M305, the ESMVD give the conclusion that bearing of the motor may be defected. On the contrary, the present data show that the motor has very high temperature on casing. The inspection found loose connection in the power box. Moreover, high level of vibration in the load side is found as well. It is the limitation of the ESMVD that can not give the correct conclusion if the supply connection is loosened. To identify such a symptom, frequency analyzer has to be employed.

On the other hand, 2 actual cases are proved only the bearing defect status. When the high vibration level was found high, motors were sent to workshop for overhaul work. Bearings were changed before the motors were reinstalled. The measurement were taken again. The result is vibration level is significantly decreased.

The rest 2 cases of historical data are proved that the high vibration level come from more than one sources. When the validation was taken, the expert system give a symptom of bearing defect was suspected. Due to the shutdown schedule, the machines were un-reluctant sent to workshop for overhaul. Bearings were changed and machines are reinstalled again. Vibration measurement was taken. The amplitude was lower than before overhaul, but the level of amplitude still indicate the problem in machine. After inspection and testing again, the machines were found that high

vibration level came from load side, which were water pump. The bearing of water pump were also defect. So, it sent vibration signal through the coupling. In such cases, the expert system can provide only bearing defect.

## 5.3 Validation Process for Spectrum Analysis

By the same procedures, the user starts the ESMVD for spectrum validation process. Technicians will bring the spectrum from both historical record and present spectrum.

### 5.3.1 Example of spectrum in validation process

Hereunder are the spectrums used for validation process.

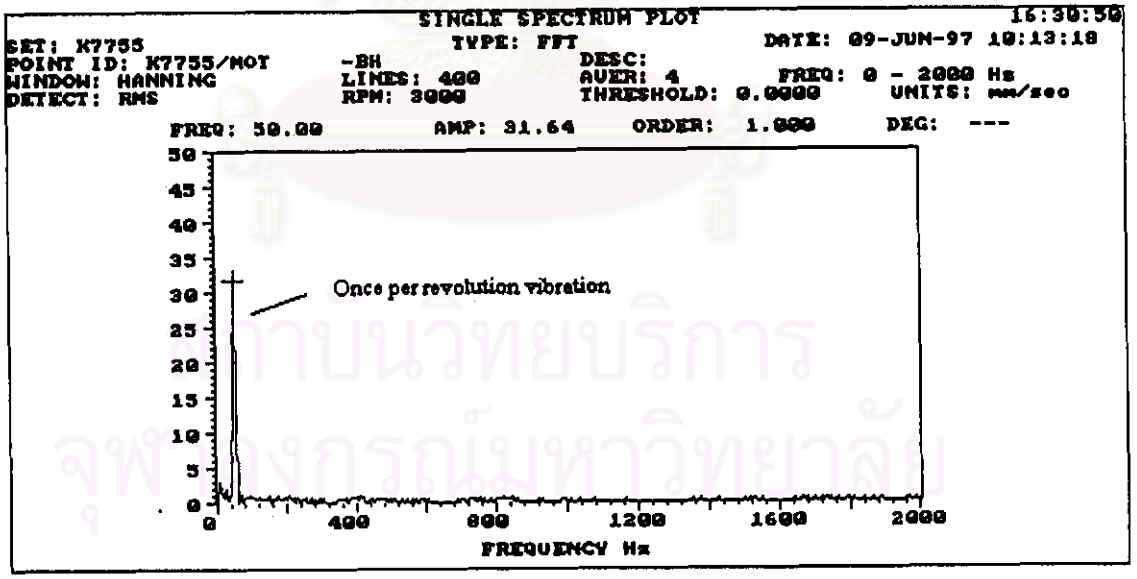


Figure 5.7 High 1X running speed

Source: Steven [27]

In figure 5.7, the vibration data of the motor of an overhung fan assembly indicated the worst recorded once per revolution vibration to be at the motor drive end horizontal direction with amplitude of 30 mm/s rms

With the same process as overall value, the ESMVD asked technician to fill basic data before series of question were asked. It start with 'Does this machine have coupling?' as shown in figure 5.8.

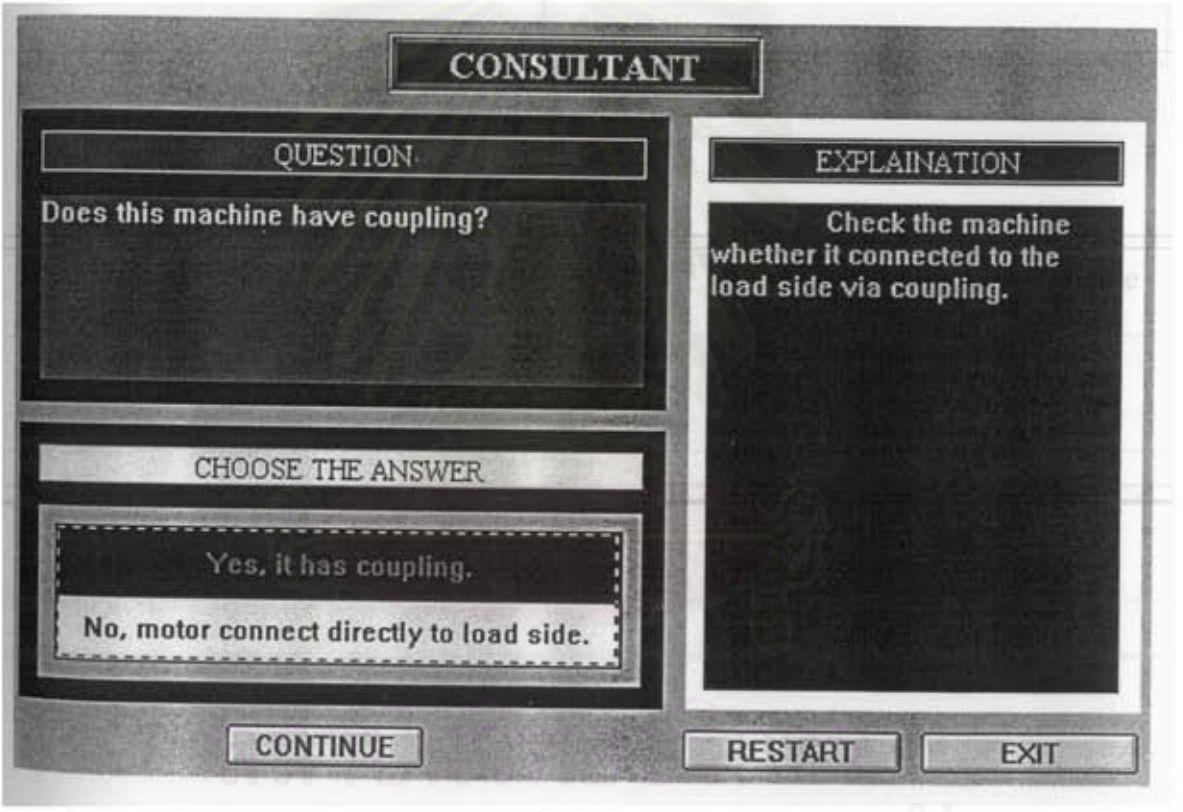


**Figure 5.8** Interactive display in Spectrum Analysis

Since the motor connected directly to the overhung fan, the answer for coupling is no. Next, the series of questions will be asked as shown in figure 5.9.

**ESMVD :** "Is there dominant peak 1X of actual speed in radial axis?"

***User:*** *"Yes"*

**ESMVD :** "Is there dominant peak 2X of actual speed in radial axis?"

***User:*** *"No"*

**ESMVD :** "Are there three or more synchronous low band?"

***User:*** *"Less than three or not have"*

**ESMVD :** "Are there any accompanying harmonics 3X to 6X in radial plane?"

***User:*** *"No"*

**Figure 5.9** Series of question

Then, the conclusion from the ESMVD come out as show in figure 5.10.

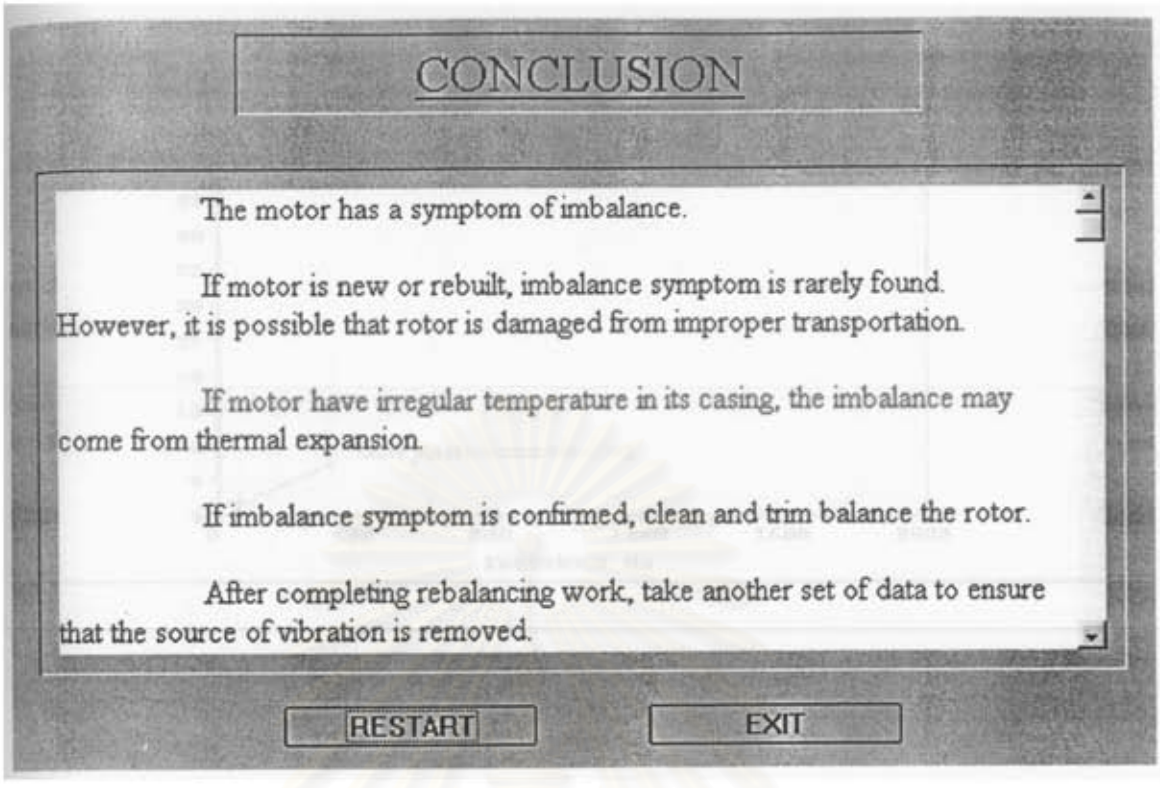


**Figure 5.10** Conclusion from ESMVD

The imbalance symptom is concluded from the ESMVD. From historical record. The motor was sent to rebalance. Then, it was measure again after balancing shaft as shown in figure 5.11.

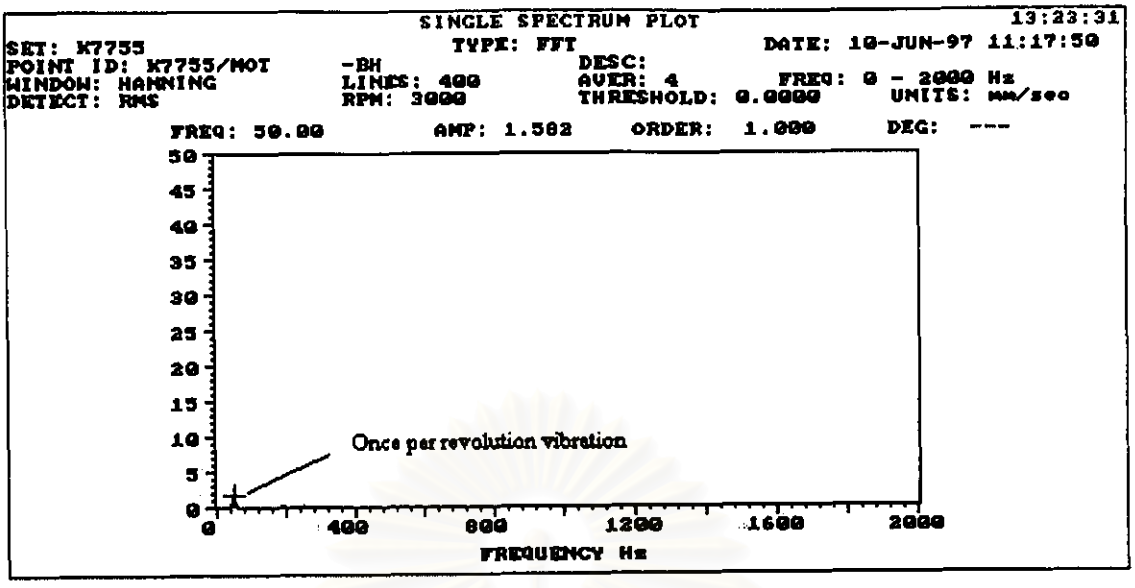


**Figure 5.11** Spectrum after balancing shaft [27]

The ESMVD is proved successfully to give a reliable an accuracy conclusion. The peak of 1X running speed is significantly deceased after balancing motor's shaft. It can be concluded that motor's shaft is imbalance as ESMVD gave a conclusion.

### 5.3.2 Another case for validation process.

By the same process as show in 5.3.1, the cases in figure 5.12 can validate the ESMVD.

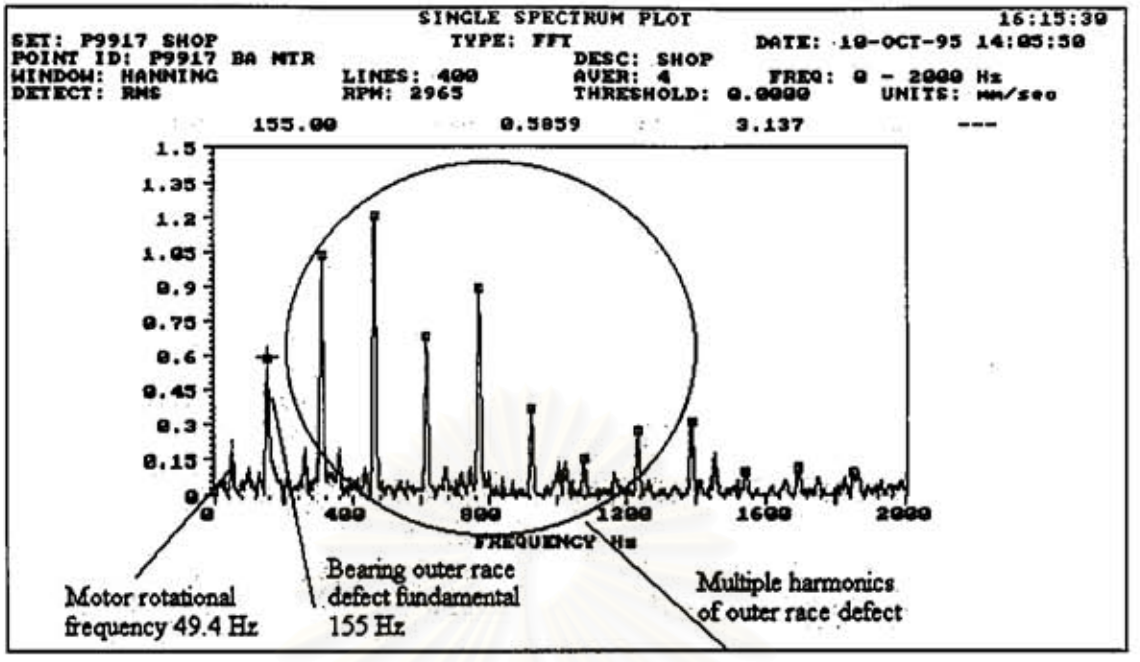


**Figure 5.12** bearing outer race defect [27]

ESMVD give a conclusion that the outer race of the bearing defect since the BPFO (155Hz) is shown. It is proved by the flaw on the outer race of the bearing as shown in figure 5.13.

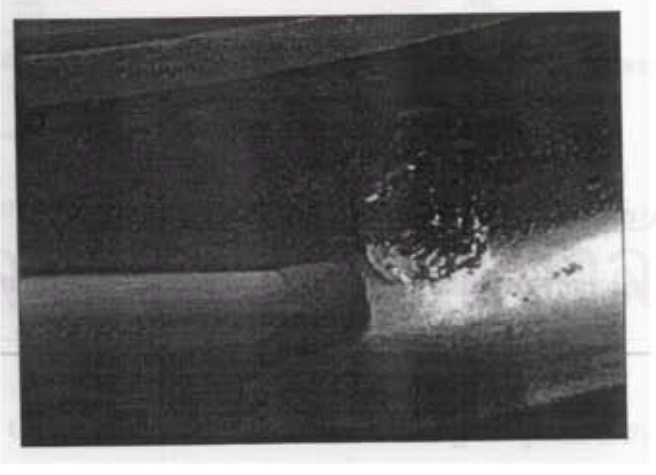

**Figure 5.13** Flaw on the outer race of the bearing [27]

### 5.3.3 conclusion for spectrum validation

The two historical cases successfully validated the ESMVD. The expert system show the capability of providing the accurately answer and recommendation. There are another cases for validation the spectrum analysis. The data is kept in the maintenance database of the paper manufacturing plant. The validation process is conducted on site. Unfortunately, output of the frequency analyzer was not allowed to print. The cases are SCR failure and inner race defect. Both are the present data at the paper manufacturing plant.

In the case of SCR fault, the 75 kW motor that drives paper scattering shows dominant peak in its spectrum: high frequency at SCR firing frequency. The ESMVD, again, ask the series of question from user before give the conclusion. Then, the motor was stopped and its speed controller was inspected. One of the SCRS was found failure. The failure SCR was replaced with the new one. After that, the motor is measured again; peak at SCR firing frequency disappears.

In another case, the 11 kW motor driving belt conveyor shows small peak at BPFI frequency on its vibration spectrum. It is not dominant. However, the responsible engineer orders technician to shorten the maintenance period. In this case, the ESMVD give a conclusion that motor is normal: no failure symptom is shown.

Unfortunately, the motor is sent to overhaul during the plant's shutdown period without any exists of obvious failure signal. Because the motors run almost continuously, when there is a chance to maintenance motor during plant shutdown period, it will be sent to inspect and overhaul without waiting for signal of failure.

This is the good example to show the limitation of condition based maintenance which rely heavily on vibration analysis.

## 5.4 Conclusion for Validation

From the validation process, the ESMVD can give the effective and reliable conclusion, both in overall value and vibration spectrum. It satisfies user with the given explanation in each display and multi color technique. Moreover, the conclusion come out quite correctly when compare with the actual data. However, the limitations of the ESMVD are found in validation process. They are show as below.

1. The ESMVD can not analyze the vibration signal from load side.
2. The ESMVD can not forecast the possibly failure time since it does not contain trend analysis function.

The two limitations can be eliminated by further improvement. Analyze vibration from load side can be done if the knowledge base is added with new knowledge of motor load. In doing so, the scope of the expert system should be carefully considered because there are many different types of load using in different manufacturing plant. Further development of the expert system should be done in specific manufacturing plant to prevent oversize of rule based; the oversize will consume more time and more step to give the conclusion.

However, more limitations may be found later if the cases for validation process are more available. The maintenance policy of the two studied manufacturing plant is still preventive maintenance-not predictive maintenance nor condition based

monitoring. Therefore, they would not take a risk to let the motor operate nearly breakdown status. Earlier taking action is always employed; the case that can prove assumption of the expert system is scarce.

In addition, comments from technician are the ESMVD does not support Thai font. It may be difficult for some technician to understand the comments and recommendations presented in the ESMVD.