REFERENCES

[1] Asuwapongpatana, S. ***Development of an air conditioning expert system.*** Master Thesis, Chulalongkorn University, 1989.

[2] Atirakapvarodom, S. ***An expert system for trouble shooting of the vertical solder coated leveling process of a printed circuit board.*** Master Thesis, Chulalongkorn University, 1995.

[3] Bentotage, S.N. ***Expert system for schedule and control of highway construction projects.*** Master Thesis, Asian Institute of Technology, 1992.

[4] Boonchukuson, K., Chaiyapinan, S., Khunapanichakij, C. ***Vibration Analysis.*** Bangkok: Technology Promotion Association (Thailand-Japan), 1997.

[5] Chindratana, D. ***An expert system for production planning in printed circuit board plant.*** Master Thesis, Chulalongkorn University, 1990.

[6] Chutima, S., Sagara, K. ***An application of vibration condition monitoring of rolling bearings in maintenance planning.*** King Mongkut Institute of Technology, Thonburi campus, Mechanical Seminar, 1990.

[7] Coastal Video Communication Corporation. ***Vibration Analysis in AC Induction Motor [VIDEO].*** 1996.

[8] Fitzgerald, A.E., Kingsley JR., C., Umans, S. D. ***Electric Machinery.*** fifth edition. (n.p.): McGrawHill, 1990.

REFERENCES (continue)

[9] Hufemia, E.P. ***An Expert System for the manufacturing design of precast concrete panels.*** Master Thesis, Asian Institute of Technology, 1996.

[10] International Oraganization for Standardization. ***ISO 10816: Mechanical Vibration - Evaluation of machine vibration by measurements on non-rotating part,*** 1995.

[11] Information Builders. ***The Level5 Object: getting started guide.*** Information Builders, Inc, 1995.

[12] Jiaranuchart, C. ***An expert system for the evaluation of telephone switching systems.*** Master Thesis, Chulalongkorn University, 1994.

[13] Julavisatkul, R. ***Vibration analysis by Neural Network.*** Master Thesis, Chulalongkorn University, 1994.

[14] Juneja, N. ***An Expert System for diagnoses of CNC Machines: using default reasoning.*** Master Thesis, Asian Institute of Technology, 1991.

[15] Lawrie, R.J. ***Understanding vibration analysis for longer motor life.*** Electrical Construction & Maintenance. 92(2): Feb 1993. 18 (2)

[16] Nitikunkasem, P. ***Expert System for Maintenance Management.*** Master Thesis, Asian Institue of Technology, 1992.

REFERENCES (continue)

[17] Pattankooha, P. ***A decision support system for overhauling power circuit breakers in a substation.*** Master Thesis, Chulalongkorn University, 1995.

[18] Pochana, K. ***Decision Support Systems for Production Planning in Chicken Processing Plant.*** Master Thesis, Chulalongkorn University, 1991.

[19] Rulesmachine ***The Level5 Object online user manual.***
http://www.rulesmachine.com

[20] Shuyu, C. ***Expert System for diagnosising A5-AXIS CNC milling machine: a case study.*** Master Thesis, Asian Institue of Technology, 1997.

[21] SKF Condition Monitoring, Inc. ***Vibration Diagnosis Guide.*** SKF's training document, 1994.

[22] Sondhi, K. ***An Expert System for the Assembly Planning of Rotational Components.*** Master Thesis, Asian Institue of Technology, 1996.

[23] Sue, S. ***An expert system for plastics processing methods selection.***
Master Thesis, Chulalongkorn University, 1995.

[24] Troyer, D. ***Let's Integrate Oil Analysis and Vibration Analysis.***
www.oilanalysis.com

[25] Ubolriabroy, P. ***Development of an expert system for determining cost of ornamental rings.*** Master Thesis, Chulalongkorn University, 1992.

REFERENCES (continue)

[26] Vongderri, B. ***Expert System for diagnosis of the operations of industrial fire tube boiler up to 10-ton capacity.*** Master Thesis, Chulalongkorn University, 1990.

[27] http://www.ukonline.co.uk/d.stevens2/vibration/ (Jan 1999)

[28] http://computingcentral.msn.com/Topics/ai/questions.asp (Jan 1999)

[29] http://www.bus.orst.edu/faculty/brownc/eswa/absvol2.htm (Jan 1999)

[30] http://www.cage.curtin.edu.au/mechanical/info/vibrations/tut1.htm (Jan 1999)

[31] http://encarta.msn.com/index/conciseindex/4C/04CAB000.htm?z=1&pg=2&br=1 (Jan 1999)

[32] http://www.cee.hw.ac.uk/~alison/ai3notes/all.html (Jan 1999)

[33] http://www.corvib.com/vibration/vibration.htm (Jan 1999)

Appendix A

Rules for Overall Value Analysis

Hereunder are the rules for overall value on time domain analysis. The first three rules are for categorizing value into table class. Next, rule number 004 to 136 classify motor into severity level. Then, rule number 137 to rule number 222 are used for point out possible symptom of failure.

```
RULE 001 table1
 IF mount OF mounting IS horizontal with coupling
THEN tables OF table class IS table1 := TRUE

RULE 002 table2
IF mount OF mounting IS horizontal with overhung
THEN tables OF table class IS table2 := TRUE

RULE 003 table3
IF mount OF mounting IS vertical
THEN tables OF table class IS table3 := TRUE
```

```
RULE 004 class1
IF power OF physical < 15
THEN class OF table class IS class1 := TRUE

RULE 005 class2
IF power OF physical >= 15
AND power OF physical < 75
THEN class OF table class IS class2 := TRUE

RULE 006 class3
IF power OF physical >= 75
THEN class OF table class IS class3 := TRUE

RULE 101 hor good class1
IF class OF table class IS class1
AND ((hor drive OF normal + hor drive OF measured) <= 0.71 OR (hor non OF
normal + hor non OF measured) <= 0.71)
THEN hor OF severity IS good := TRUE
AND pen color OF textbox 28 := 0,255,0
AND text OF textbox 28 := "good"

RULE 102 hor sat class1
IF class OF table class IS class1
AND (hor drive OF normal + hor drive OF measured) > 0.71
```

```
AND (hor drive OF normal + hor drive OF measured) <= 1.8
THEN hor OF severity IS satisfactory := TRUE
AND pen color OF textbox 28 := 0,0,255
AND text OF textbox 28 := "satisfactory"

RULE 103 hor unsat class1
IF class OF table class IS class1
AND (hor drive OF normal + hor drive OF measured) > 2.8
AND (hor drive OF normal + hor drive OF measured) <= 4.5
THEN hor OF severity IS unsatisfactory := TRUE
AND pen color OF textbox 28 := 255,255,0
AND text OF textbox 28 := "unsatisfactory"
AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 30])

RULE 104 hor unacc class1
IF class OF table class IS class1
AND (hor drive OF normal + hor drive OF measured) > 4.5
AND (hor drive OF normal + hor drive OF measured) <= 45
THEN hor OF severity IS unacceptable := TRUE
AND pen color OF textbox 28 := 255,0,0
AND text OF textbox 28 := "unacceptable"
AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 31])

RULE 105 hor good class2
IF class OF table class IS class2
```

```
AND (hor drive OF normal + hor drive OF measured) <= 1.12
THEN hor OF severity IS good := TRUE
AND pen color OF textbox 28 := 0,255,0
AND text OF textbox 28 := "good"

RULE 106 hor sat class2
IF class OF table class IS class2
AND (hor drive OF normal + hor drive OF measured) > 1.12
AND (hor drive OF normal + hor drive OF measured) <= 2.8
THEN hor OF severity IS satisfactory := TRUE
AND pen color OF textbox 28 := 0,0,255
AND text OF textbox 28 := "satisfactory"

RULE 107 hor unsat class2
IF class OF table class IS class2
AND (hor drive OF normal + hor drive OF measured) > 2.8
AND (hor drive OF normal + hor drive OF measured) <= 7.1
THEN hor OF severity IS unsatisfactory := TRUE
AND pen color OF textbox 28 := 255,255,0
AND text OF textbox 28 := "unsatisfactory"
AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 30])

RULE 108 hor unacc class2
IF class OF table class IS class2
AND (hor drive OF normal + hor drive OF measured) > 7.1
```

```
AND (hor drive OF normal + hor drive OF measured) <= 45
THEN hor OF severity IS unacceptable := TRUE
AND pen color OF textbox 28 := 255,0,0
AND text OF textbox 28 := "unacceptable"
AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 31])

RULE 109 hor good class3
IF class OF table class IS class3
AND (hor drive OF normal + hor drive OF measured) <= 1.8
THEN hor OF severity IS good := TRUE
AND pen color OF textbox 28 := 0,255,0
AND text OF textbox 28 := "good"

RULE 110 hor sat class3
IF class OF table class IS class3
AND (hor drive OF normal + hor drive OF measured) > 1.8
AND (hor drive OF normal + hor drive OF measured) <= 4.5
THEN hor OF severity IS satisfactory := TRUE
AND pen color OF textbox 28 := 0,0,255
AND text OF textbox 28 := "satisfactory"

RULE 111 hor unsat class3
IF class OF table class IS class3
AND (hor drive OF normal + hor drive OF measured) > 4.5
AND (hor drive OF normal + hor drive OF measured) <= 11.2
```

```
THEN hor OF severity IS unsatisfactory := TRUE
AND pen color OF textbox 28 := 255,255,0
AND text OF textbox 28 := "unsatisfactory"
AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 30])

RULE 112 hor unacc class3
IF class OF table class IS class3
AND (hor drive OF normal + hor drive OF measured) > 11.2
AND (hor drive OF normal + hor drive OF measured) <= 45
THEN hor OF severity IS unacceptable := TRUE
AND pen color OF textbox 28 := 255,0,0
AND text OF textbox 28 := "unacceptable"
AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 31])

RULE 113 ver good class1
IF class OF table class IS class1
AND (ver drive OF normal + ver drive OF measured) <= 0.71
THEN ver OF severity IS good := TRUE
AND pen color OF textbox 29 := 0,255,0
AND text OF textbox 29 := "good"

RULE 114 ver sat class1
IF class OF table class IS class1
AND (ver drive OF normal + ver drive OF measured) > 0.71
AND (ver drive OF normal + ver drive OF measured) <= 1.8
```

```
THEN ver OF severity IS satisfactory := TRUE
AND pen color OF textbox 29 := 0,0,255
AND text OF textbox 29 := "satisfactory"


RULE 115 ver unsat class1
IF class OF table class IS class1
AND (ver drive OF normal + ver drive OF measured) > 2.8
AND (ver drive OF normal + ver drive OF measured) <= 4.5
THEN ver OF severity IS unsatisfactory := TRUE
AND pen color OF textbox 29 := 255,255,0
AND text OF textbox 29 := "unsatisfactory"
AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 32])


RULE 116 ver unacc class1
IF class OF table class IS class1
AND (ver drive OF normal + ver drive OF measured) > 4.5
AND (ver drive OF normal + ver drive OF measured) <= 45
THEN ver OF severity IS unacceptable := TRUE
AND pen color OF textbox 29 := 255,0,0
AND text OF textbox 29 := "unacceptable"
AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 33])


RULE 117 ver good class2
IF class OF table class IS class2
AND (ver drive OF normal + ver drive OF measured) <= 1.12
```

```
THEN ver OF severity IS good := TRUE
AND pen color OF textbox 29 := 0,255,0
AND text OF textbox 29 := "good"


RULE 118 ver sat class2
IF class OF table class IS class2
AND (ver drive OF normal + ver drive OF measured) > 1.12
AND (ver drive OF normal + ver drive OF measured) <= 2.8
THEN ver OF severity IS satisfactory := TRUE
AND pen color OF textbox 29 := 0,0,255
AND text OF textbox 29 := "satisfactory"


RULE 119 ver unsat class2
IF class OF table class IS class2
AND (ver drive OF normal + ver drive OF measured) > 2.8
AND (ver drive OF normal + ver drive OF measured) <= 7.1
THEN ver OF severity IS unsatisfactory := TRUE
AND pen color OF textbox 29 := 255,255,0
AND text OF textbox 29 := "unsatisfactory"
AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 32])


RULE 120 ver unacc class2
IF class OF table class IS class2
AND (ver drive OF normal + ver drive OF measured) > 7.1
AND (ver drive OF normal + ver drive OF measured) <= 45
```

```
THEN ver OF severity IS unacceptable := TRUE
AND pen color OF textbox 29 := 255,0,0
AND text OF textbox 29 := "unacceptable"
AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 33])

RULE 121 ver good class3
IF class OF table class IS class3
AND (ver drive OF normal + ver drive OF measured) <= 1.8
THEN ver OF severity IS good := TRUE
AND pen color OF textbox 29 := 0,255,0
AND text OF textbox 29 := "good"

RULE 122 ver sat class3
IF class OF table class IS class3
AND (ver drive OF normal + ver drive OF measured) > 1.8
AND (ver drive OF normal + ver drive OF measured) <= 4.5
THEN ver OF severity IS satisfactory := TRUE
AND pen color OF textbox 29 := 0,0,255
AND text OF textbox 29 := "satisfactory"

RULE 123 ver unsat class3
IF class OF table class IS class3
AND (ver drive OF normal + ver drive OF measured) > 4.5
AND (ver drive OF normal + ver drive OF measured) <= 11.2
THEN ver OF severity IS unsatisfactory := TRUE
```

```
AND pen color OF textbox 29 := 255,255,0

AND text OF textbox 29 := "unsatisfactory"

AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 32])


RULE 124 ver unacc class3

IF class OF table class IS class3

AND (ver drive OF normal + ver drive OF measured) > 11.2

AND (ver drive OF normal + ver drive OF measured) <= 45

THEN ver OF severity IS unacceptable := TRUE

AND pen color OF textbox 29 := 255,0,0

AND text OF textbox 29 := "unacceptable"

AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 33])


RULE 125 axial good class1

IF class OF table class IS class1

AND (axial drive OF normal + axial drive OF measured) <= 0.71

THEN axial OF severity IS good := TRUE

AND pen color OF textbox 30 := 0,255,0

AND text OF textbox 30 := "good"


RULE 126 axial sat class1

IF class OF table class IS class1

AND (axial drive OF normal + axial drive OF measured) > 0.71

AND (axial drive OF normal + axial drive OF measured) <= 1.8

THEN axial OF severity IS satisfactory := TRUE
```

```
AND pen color OF textbox 30 := 0,0,255
AND text OF textbox 30 := "satisfactory"

RULE 127 axial unsat class1
IF class OF table class IS class1
AND (axial drive OF normal + axial drive OF measured) > 2.8
AND (axial drive OF normal + axial drive OF measured) <= 4.5
THEN axial OF severity IS unsatisfactory := TRUE
AND pen color OF textbox 30 := 255,255,0
AND text OF textbox 30 := "unsatisfactory"
AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 34])

RULE 128 axial unacc class1
IF class OF table class IS class1
AND (axial drive OF normal + axial drive OF measured) > 4.5
AND (axial drive OF normal + axial drive OF measured) <= 45
THEN axial OF severity IS unacceptable := TRUE
AND pen color OF textbox 30 := 255,0,0
AND text OF textbox 30 := "unacceptable"
AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 35])

RULE 129 axial good class2
IF class OF table class IS class2
AND (axial drive OF normal + axial drive OF measured) <= 1.12
THEN axial OF severity IS good := TRUE
```

```
AND pen color OF textbox 30 := 0,255,0
AND text OF textbox 30 := "good"

RULE 130 axial sat class2
IF class OF table class IS class2
AND (axial drive OF normal + axial drive OF measured) > 1.12
AND (axial drive OF normal + axial drive OF measured) <= 2.8
THEN axial OF severity IS satisfactory := TRUE
AND pen color OF textbox 30 := 0,0,255
AND text OF textbox 30 := "satisfactory"

RULE 131 axial unsat class2
IF class OF table class IS class2
AND (axial drive OF normal + axial drive OF measured) > 4.5
AND (axial drive OF normal + axial drive OF measured) <= 11.2
THEN axial OF severity IS unsatisfactory := TRUE
AND pen color OF textbox 30 := 255,255,0
AND text OF textbox 30 := "unsatisfactory"
AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 34])

RULE 132 axial unacc class2
IF class OF table class IS class2
AND (axial drive OF normal + axial drive OF measured) > 7.1
AND (axial drive OF normal + axial drive OF measured) <= 45
THEN axial OF severity IS unacceptable := TRUE
```

```
AND pen color OF textbox 30 := 255,0,0
AND text OF textbox 30 := "unacceptable"
AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 35])

RULE 133 axial good class3
IF class OF table class IS class3
AND (axial drive OF normal + axial drive OF measured) <= 1.8
THEN axial OF severity IS good := TRUE
AND pen color OF textbox 30 := 0,255,0
AND text OF textbox 30 := "good"

RULE 134 axial sat class3
IF class OF table class IS class3
AND (axial drive OF normal + axial drive OF measured) > 1.8
AND (axial drive OF normal + axial drive OF measured) <= 4.5
THEN axial OF severity IS satisfactory := TRUE
AND pen color OF textbox 30 := 0,0,255
AND text OF textbox 30 := "satisfactory"

RULE 135 axial unsat class3
IF class OF table class IS class3
AND (axial drive OF normal + axial drive OF measured) > 4.5
AND (axial drive OF normal + axial drive OF measured) <= 11.2
THEN axial OF severity IS unsatisfactory := TRUE
AND pen color OF textbox 30 := 255,255,0
```

```
AND text OF textbox 30 := "unsatisfactory"
AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 34])

RULE 136 axial unacc class3
IF class OF table class IS class3
AND (axial drive OF normal + axial drive OF measured) > 11.2
AND (axial drive OF normal + axial drive OF measured) <= 45
THEN axial OF severity IS unacceptable := TRUE
AND pen color OF textbox 30 := 255,0,0
AND text OF textbox 30 := "unacceptable"
AND text OF textbox 76 := CONCAT( text OF textbox 76, status[ 35])

RULE 201 bearing unsat
IF hor OF severity IS unsatisfactory
OR ver OF severity IS unsatisfactory
OR axial OF severity IS unsatisfactory
THEN unsat OF bearing
AND text OF textbox 75 := status[ 38]
AND text OF textbox 73 := time[ 38] OF conclusion 1

RULE 202 bearing unaccept
IF hor OF severity IS unacceptable
OR ver OF severity IS unacceptable
OR axial OF severity IS unacceptable
THEN unaccept OF bearing
```

```
AND text OF textbox 75 := status[ 39]
AND text OF textbox 73 := time[ 39] OF conclusion 1

RULE 203 horshaft imbalance
IF mount OF mounting IS horizontal with coupling
AND (hor OF severity IS unsatisfactory OR hor OF severity IS unacceptable)
AND NOT (ver OF severity IS unsatisfactory OR ver OF severity IS unacceptable OR
axial OF severity IS unsatisfactory OR axial OF severity IS unacceptable)
THEN imbalance OF symptom := TRUE
AND text OF textbox 75 := status[ 1]
AND text OF textbox 73 := time[ 1] OF conclusion 1

RULE 204 horshaft misalignment
IF mount OF mounting IS horizontal with coupling
AND (ver OF severity IS unsatisfactory OR ver OF severity IS unacceptable)
AND (axial OF severity IS unsatisfactory OR axial OF severity IS unacceptable)
AND NOT (hor OF severity IS unsatisfactory OR hor OF severity IS unacceptable)
THEN misalignment OF symptom := TRUE
AND text OF textbox 75 := status[ 2]
AND text OF textbox 73 := time[ 2] OF conclusion 1

RULE 205 horshaft looseness
IF mount OF mounting IS horizontal with coupling
AND (hor OF severity IS unsatisfactory OR hor OF severity IS unacceptable)
AND (ver OF severity IS satisfactory OR ver OF severity IS unsatisfactory)
```

```
AND NOT (axial OF severity IS unsatisfactory OR axial OF severity IS unacceptable)
THEN looseness OF symptom := TRUE
AND text OF textbox 75 := status[ 3]
AND text OF textbox 73 := time[ 3] OF conclusion 1

RULE 206 horshaft overhung imbalance and misaglignment
IF mount OF mounting IS horizontal with overhung
AND (hor OF severity IS unsatisfactory OR hor OF severity IS unacceptable)
AND (axial OF severity IS unsatisfactory OR axial OF severity IS unacceptable)
AND NOT (ver OF severity IS unsatisfactory OR ver OF severity IS unacceptable)
THEN imbalance OF symptom := TRUE
AND text OF textbox 75 := status[ 4]
AND text OF textbox 73 := time[ 4] OF conclusion 1

RULE 207 horshaft overhung looseness
IF mount OF mounting IS horizontal with overhung
AND (hor OF severity IS unsatisfactory OR hor OF severity IS unacceptable)
AND (ver OF severity IS satisfactory OR ver OF severity IS unsatisfactory)
AND NOT (axial OF severity IS unsatisfactory OR axial OF severity IS unacceptable)
THEN looseness OF symptom := TRUE
AND text OF textbox 75 := status[ 6]
AND text OF textbox 73 := time[ 6] OF conclusion 1

RULE 208 vershaft imbalance and looseness
IF mount OF mounting IS vertical
```

```
AND (hor OF severity IS unsatisfactory OR hor OF severity IS unacceptable)
AND NOT (axial OF severity IS unsatisfactory OR axial OF severity IS unacceptable)
THEN imbalance OF symptom := TRUE
AND text OF textbox 75 := status[ 7]
AND text OF textbox 73 := time[ 7] OF conclusion 1

RULE 209 vershaft misalignment
IF mount OF mounting IS vertical
AND (hor OF severity IS unsatisfactory OR hor OF severity IS unacceptable)
AND (axial OF severity IS unsatisfactory OR axial OF severity IS unacceptable)
AND NOT (ver OF severity IS unsatisfactory OR ver OF severity IS unacceptable)
THEN misalignment OF symptom := TRUE
AND text OF textbox 75 := status[ 8]
AND text OF textbox 73 := time[ 8] OF conclusion 1

RULE 220 machine OK
IF (hor OF severity IS good OR hor OF severity IS satisfactory)
AND (ver OF severity IS good OR ver OF severity IS satisfactory)
AND (axial OF severity IS good OR axial OF severity IS satisfactory)
AND (hor drive OF measured > 0 OR ver drive OF measured > 0 OR axial drive OF
measured > 0 OR hor non OF measured > 0 OR ver non OF measured > 0 OR axial
non OF measured > 0)
THEN machine OK OF symptom := TRUE
AND text OF textbox 75 := status[ 40]
AND text OF textbox 73 := time[ 40] OF conclusion 1
```

RULE 222 undetermine

IF (mount OF mounting IS horizontal with coupling AND NOT (ver OF severity IS unsatisfactory OR ver OF severity IS unacceptable) AND (hor OF severity IS unsatisfactory OR hor OF severity IS unacceptable) AND (axial OF severity IS unsatisfactory OR axial OF severity IS unacceptable))

OR (mount OF mounting IS horizontal with overhung AND NOT (hor OF severity IS unsatisfactory OR hor OF severity IS unacceptable) AND (ver OF severity IS unsatisfactory OR ver OF severity IS unacceptable) AND (axial OF severity IS unsatisfactory OR axial OF severity IS unacceptable))

OR (mount OF mounting IS vertical AND NOT (hor OF severity IS unsatisfactory OR hor OF severity IS unacceptable OR ver OF severity IS unsatisfactory OR ver OF severity IS unacceptable) AND (axial OF severity IS unsatisfactory OR axial OF severity IS unacceptable))

THEN machine OK OF symptom

AND text OF textbox 75 := status[10]

AND text OF textbox 73 := time[10] OF conclusion 1

Appendix B

Rule Base for Vibration Spectrum

RULE 301 misalignment

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

RULE 302 misalignment CF85

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

RULE 303 misalignment CF70

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

RULE 310 soft foot

IF RPM1X OF radial spectrum

AND RPM2X OF radial spectrum

AND RPM1X peak smaller than RPM2X OF horizontal s

THEN soft foot OF spectrum symptom

RULE 320 imbalance

IF RPM1X OF radial spectrum

AND NOT harmonics OF radial spectrum

THEN imbalance CF70 OF spectrum symptom

RULE 321 imbalance

IF live OF coupling

AND RPM1X OF radial spectrum

AND RPM1X OF axial spectrum

THEN imbalance CF70 OF spectrum symptom

RULE 322 imbalance

IF RPM1X OF radial spectrum

THEN imbalance CF60 OF spectrum symptom

RULE 323 imbalance

IF RPM1X OF radial spectrum

AND diff in radial OF amplitude
THEN imbalance CF50 OF spectrum symptom
AND eccentric rotor OF spectrum symptom CF 50

RULE 330 looseness
IF RPM1X OF radial spectrum AND RPM2X OF radial spectrum
AND harmonics OF radial spectrum
AND greater than 20% RPM1X OF amplitude
AND (subharmonics multiples OF radial spectrum OR sporadic harmonics OF radial spectrum)
THEN looseness CF85 OF spectrum symptom CF 85
AND imbalance CF70 OF spectrum symptom CF 20
AND misalignment CF85 OF spectrum symptom CF 20

RULE 340 bearing defect
IF BPFO OF bearing AND BPFI OF bearing
THEN bearing defect OF spectrum symptom

RULE 341 inner race
IF BPFI OF bearing
THEN inner race defect OF spectrum symptom

RULE 342 outer race
IF BPFO OF bearing
THEN outer race defect OF spectrum symptom

RULE 350 rotor rub

IF rotor rub CF70 OF spectrum symptom

AND (high energy band OF band OR subsynchronous energy band OF band)

THEN rotor rub CF70 OF spectrum symptom

RULE 351 rotor rub

IF RPM1X OF radial spectrum

AND nonsynchronous low band peak OF band

AND (one half of peak OF band OR one third of peak OF band)

THEN rotor rub CF60 OF spectrum symptom

RULE 360 coupling problem

IF live OF coupling

AND flexible OF coupling

AND RPM1X OF axial spectrum

AND RPM2X OF radial spectrum

AND (linear increase OF history OR curving increase OF history)

THEN coupling CF75 OF spectrum symptom

RULE 361 coupling problem

IF live OF coupling

AND flexible OF coupling

AND RPM1X OF axial spectrum

AND RPM2X OF radial spectrum

THEN coupling CF65 OF spectrum symptom

RULE 362 coupling problem

IF live OF coupling

AND flexible OF coupling

AND (linear increase OF history OR curving increase OF history)

THEN coupling CF60 OF spectrum symptom

RULE 363 coupling problem

IF live OF coupling

AND flexible OF coupling

AND RPM1X OF axial spectrum

THEN coupling CF50 OF spectrum symptom

RULE 370 rotor eccentricity

IF twice of line frequency OF electrical

AND side band around 2FL OF electrical

AND modulation of pole pass frequency OF electrical

AND pole pass frequency OF electrical

THEN electrical fault2 OF spectrum symptom

RULE 371 stator problem

IF twice of line frequency OF electrical

THEN stator problem OF spectrum symptom

RULE 373 SCR fault

IF variable speed OF control

AND show firing frequency OF SCR

THEN SCR fault OF spectrum symptom

RULE 380 broken or loose wires

IF twice of line frequency OF electrical

AND one third FL side band around 2FL OF electrical

THEN broken or loose wires OF spectrum symptom

RULE 390 bent shaft & eccentric rotor

IF RPM1X OF axial spectrum

AND other end 1X OF axial spectrum

THEN bent shaft OF spectrum symptom CF 70

AND eccentric rotor OF spectrum symptom CF 100

RULE 391 bent shaft

IF RPM1X OF axial spectrum

THEN bent shaft OF spectrum symptom CF 50

RULE 400 multisymptom

IF live OF coupling

AND rigid OF coupling

AND (RPM2X OF fundamental OR RPM2X OF vertical spect)

THEN misalignment CF50 OF spectrum symptom

```
AND looseness CF50 OF spectrum symptom

RULE 401 multisymptom
IF three or more synchronous running speed OF band
AND amplitude greater than 20% of 1X OF band
THEN looseness CF85 OF spectrum symptom
AND misalignment CF85 OF spectrum symptom CF 20
AND imbalance CF70 OF spectrum symptom CF 20

RULE 99 machine OK
IF NOT other frequency OF dominant
THEN machine ok OF physical

DEMON 01 misalignment
IF misalignment OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 1] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 02 misalignment
IF misalignment CF85 OF spectrum symptom
THEN visible OF main window := FALSE
```

```
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 2] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 03 misalignment
IF misalignment CF70 OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 3] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 04 misalignment
IF misalignment CF50 OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 4] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 05 bearing defect
```

```
IF bearing defect OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 5] OF conclusion 1)
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 6] OF conclusion 1)
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 7] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 06 inner race defect
IF inner race defect OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 6] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 07 outer race defect
IF outer race defect OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
```

```
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 7] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 08 imbalance
IF imbalance CF70 OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 8] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 09 imbalance
IF imbalance CF60 OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 9] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 10 imbalance
IF imbalance CF50 OF spectrum symptom
```

```
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 10] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 11 stator problem
IF stator problem OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 11] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 12 rotor problem
IF rotor problem OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 12] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion
```

```
DEMON 13 SCR
IF SCR fault OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 13] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 14 looseness
IF looseness CF85 OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 14] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 15 looseness
IF looseness CF85 OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 15] OF conclusion 1)
```

```
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 16 coupling
IF coupling CF75 OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 16] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 17 coupling
IF coupling CF65 OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 17] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 18 coupling
IF coupling CF60 OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
```

```
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 18] OF
conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 19 coupling
IF coupling CF50 OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 19] OF
conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 20 rotor rub
IF rotor rub CF70 OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 20] OF
conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 21 rotor rub
IF rotor rub CF70 OF spectrum symptom
THEN visible OF main window := FALSE
```

```
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 21] OF
conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 22 soft foot
IF soft foot OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 22] OF
conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 23 broken or loose wires
IF broken or loose wires OF spectrum symptom
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 23] OF
conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion

DEMON 30 machine OK
```

```
IF machine ok OF physical
THEN visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 30] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion
ELSE visible OF main window := FALSE
AND visible OF spectrum recommendation window := TRUE
AND continue display OF spectrum recommendation window := TRUE
AND text OF textbox 98 := CONCAT( text OF textbox 98, frequency[ 31] OF conclusion 1)
AND output OF spectrum recommendation window := spectrum conclusion
```

Appendix C

Failure Symptom in Knowledge Base

Explanation of symptoms, taken from SKF's Prism, SKF Co., Ltd., is shown below. Some explanations are adapted and employed in the ESMVD

1. MISALIGNMENT

Misalignment occurs in a number of places in rotating machinery. Misalignment can occur within a component, between the bearings that are suspending the shaft. It can also occur between meshing gears - we refer to this as an internal gear misalignment. Generally, misalignment occurs when two components are coupled together.

Misalignment is a common fault since it can be difficult to align two shafts and their bearings properly. The three main types of shaft misalignment are angular misalignment, offset misalignment and combination misalignment.

- in angular misalignment, the center line of the two shafts meet at an angle.

- in offset misalignment, the shaft center lines are parallel but displaced from one another.

- combination misalignment, is a combination of the above.

The classic vibration signature for coupling misalignment is high vibration at 1xRPM and 2xRPM in the radial plane. Vibration authorities differ considerably on their emphasis on relative amplitudes (the amplitude at 2xRPM relative to the amplitude at 1xRPM, and on the difference in readings taken in the radial plane as opposed to the axial plane).

The use of phase measurement to verify shaft misalignment is an additional test. The data collector you are using must be capable of collecting a shaft position (using a phase kit or stroboscope) while taking a vibration reading. Phase readings taken will be 180 degrees out-of-phase across the coupling.

2. IMBALANCE

Imbalance in a shaft is caused by a physical difference between the mass centre and rotating centre of a rotor. Imbalance can be caused by a number of factors, including:

- improper manufacture of the rotor.
- a distortion of the rotor due to thermal effects.
- a build up of debris on the rotor, or on any blades or vanes suspended on the shaft. Also,

uneven wear on impellers can create a mass imbalance on the shaft.

- the addition of shaft fittings without an appropriate counterbalancing procedure.

Mass imbalance produces high vibration at 1xRPM, detected in the radial planes. Overhung machinery can sometimes produce vibration either at 2xRPM, or at 1xRPM in the axial planes., or at 1xRPM in the axial planes."

3. PHASE I BEARING CONDITION

A phase I bearing condition can be triggered by two situations. One is the presence of microscopic cracks in the rollers or balls of the bearing, tiny scratches in the inner or outer races of the bearing, or some cracking or slight distortion in the cage assembly. The second is a momentary loss of boundary lubrication in the bearing. This loss of the lubrication barrier between rolling element and raceway leads to metal-to-metal contact. The two situations are, in the context of vibration analysis, virtually indistinguishable.

Phase I bearing condition can be detected by the use of high frequency detection (HFD), envelope readings or SEE readings. If the bearing is grease lubricated, a phase I bearing condition may be a good indicator that greasing the bearing may be in order. If the bearing is oil-lubricated, and a phase I condition is persistent, the bearing lubrication system may not be performing as specified.

4. PHASE II BEARING CONDITION

A phase II bearing condition is triggered by the presence of the classic symptoms of bearing deterioration - bearing defect frequencies and their sidebands. The amount of energy in the spectrum increases, with peaks appearing at the race or ball spin frequencies and their harmonics.

In theory, the progression of bearing deterioration can be monitored by determining relative energy in the spectrum "bands" - the lower the frequency of the peaks, the worse the bearing condition. In reality, it is difficult to determine condition to such a fine level.

The use of envelope type spectra can improve the probability of detecting a bearing in phase II condition.

5. PHASE III BEARING CONDITION

A phase III bearing condition occurs when the bearing has deteriorated to a stage where complete failure is imminent. As the bearing loses its clearance and the roller/cage assembly loses its cohesion, the bearing's vibration characteristic changes from that of a rolling element bearing to a mechanically loose component. The dominant signals in the narrowband spectrum are multiples of the fundamental speed, rather than multiples of the race or ball spin frequencies. At this point, there is generally an audibl whine or growling noise coming from the bearing.

6. ROTOR RUB

Rubs are caused by a rotating element contacting a stationary element in the machine. Rubs can range from single point contact to complete contact throughout the revolution.

Rubs (especially in higher speed equipment) can be extremely damaging. The most serious rub situation is when a babitt (sleeve) bearing "wipes" - this can create high vibration, but often only for a short duration of time.

Other rub situations include shaft rubbing against seals, housings or guards. Although some vibration authorities specify than vanes/impellers contacting their housings can be considered a rub, we classify these situations separately.

The classic signature of a rub is a flattened orbit or flattened waveform - the rub prevents the shaft centre from completing its (generally elliptical) orbit. In a spectrum, a rub can manifest itself as either sub synchronous vibration or as a series of integer fraction sub harmonics of the fundamental. (i.e. 1 1/2xRPM, 1 1/3xRPM, 1 1/4xRPM etc.)

It is good to keep in mind that rubs, unlike imbalance, are generally transitory in nature - therefore, you should be more seriously concerned about a rub situation if the machine has just been installed or overhauled.

7. SCR FAULT

A silicon control rectifier (SCR) is used to vary the speed of AC multispeed and DC motors. Any excessive variation in the SCR Firing Frequency (either excessively high or abnormally low) is an indicator of a problem with the SCR. The SCR unit and its connections should be tested.

Other possible faults that can be detected through evidence found at the SCR Firing Frequency and its sidebands are broken armature windings, grounding problem, faulty motor controls and loose connections.

8. BENT SHAFT CONDITION

A bent shaft problem is possible if vibration levels are relatively high in the axial plane across the component. If phase readings are taken at both ends of the component, the readings will be 180 degrees out of phase in the axial plane. e.__ ouplings on which wear has been sufficient to ridge the teeth. Thermal growth is deterred and, thus, a vibration effect similar to misalignment takes place.

9. BROKEN ROTOR BARS

Broken or cracked rotor bars can produce the two types of peaks in vibration spectra. One, peaks appear as synchronous harmonics of the (number of rotor bars X RPM).

If the number of rotor bars is unknown, the count is usually between 35 and 55. Often the higher peak is a 2 X number of rotor bars X RPM. Another symptom of broken rotor bars in motors is a high slip or pole pass frequency relative to the line frequency on a current clamp reading. Use a current clamp with your data collector to collect a spectrum narrowly focused around the line frequency.

10. ECCENTRIC ROTOR

An eccentric rotor condition is virtually indistinguishable from an imbalance condition. An eccentric rotor is generally caused by improper manufacturer. The main indicator of eccentricity in the rotor (rather than pure imbalance) is found during an attempt to balance the rotor-the application of balance weights causes vibration to reduce in in one radial plane, but to increase in the other.

11. ELECTRICAL FAULT

Electrical faults on induction type AC motors usually generate high 2Xline frequency peaks. These problems can include such problems as stator eccentricity, insulaton gaps and/or shorted windings/laminations. Try to take a vibration reading after the power has been cut off - any peaks caused by an electrical fault should disappear immediately, peaks that are mechanical in origin should still be there (probably with reduced amplitudes - make sure you don't use averaging when you take the readings!). Another indication of an electrical fault is high temperature readings on the casing - electrical problems are often accompanied with overheating.

Appendix D

Vibration terminology

In vibration analysis, some words are specific. Fortunately, vibration institute http://www.vibinst.org/vglos_a-e.htm) provides very the useful terminology in vibration analysis. They are alphabetical sorted as shown below. Please note that some vibration terms are used in the explanation part in the ESMVD.

1. Accelerance

The frequency response function of acceleration/force. Also known as inertance.

2. Accelerometer

A transducer whose output is n electrical/mechanical directly proportional to acceleration forces. The output is usually produced by force applied to a piezoelectric crystal which generates a current proportional to the applied force. This current is then amplified and displayed as a time waveform or processed by a Fourier transform to produce a frequency display. Single integration of the acceleration signal will produce a velocity display and double integration of the acceleration signal will produce a displacement display.

3. Accuracy

How close a measurement is to the absolute quantity.

4. Acoustic Emission

The detected energy that is generated when materials are deformed or break. For rolling element bearing analysis, it is the periodic energy generated by the over rolling of particles or flaws and detected by the display of the bearing flaw frequencies.

5. Algorithm

A specific procedure for solving mathematical problems. An FFT is an algorithm.

6. Aliasing

To digitize an analog signal for processing in digital instruments such as an FFT analyzer, it first must be periodically sampled, the sampling process occurring at a specific rate called the sampling frequency. As long as the sampling frequency is more than twice as high as the highest frequency in the signal, the sampled wave will be a proper representation of the analog waveform. If, however, the sampling frequency is less than twice as high as the highest frequency to be sampled, the sampled waveform will contain extraneous components called "aliases." The generation of aliases is called aliasing.

An example of aliasing sometimes occurs in motion pictures, as for instance when the wagon wheels in a Western seem to be going backward. This is optical aliasing, caused by the fact that the frame rate of the movie camera (24 frames per second) is not fast enough to resolve the positions of the spokes. Another example of optical aliasing is the stroboscope, where a moving object is illuminated by a flashing light and can be made to appear stationary, or move backward.

Aliasing must be avoided in digital signal analysis to prevent errors, and FFT analyzers always contain low pass filters in their input stages to eliminate frequency components higher than one-half the sampling frequency. These filters are automatically tuned to the proper values as the sampling frequency is changed, and this occurs when the frequency range of the analyzer is changed.

7. Alignment

A condition whereby the axes of machine components are either coincident, parallel or perpendicular, according to design requirements, during operation.

8. Amplification Factor (Q)

The amount of mechanical gain of a structure when excited at a resonant frequency. The ratio of the amplitude of the steady state solution (amplitude at resonance) to the static deflection for the same force F. The amplification factor is a function of the system damping. For a damping ratio z =0 (no damping) the amplification factor is infinite, for z =1 (critically damped) there is no amplification.

9. Amplitude

The measurement of energy or movement in a vibrating object. Amplitude is measured and expressed in three ways: Displacement (commonly in mils Pk-Pk); Velocity (commonly in In/Sec Pk); and Acceleration (commonly in gs RMS). Amplitude is also the y-axis of the vibration time waveform and spectrum, it helps define the severity of the vibration.

10. Analog

Quantities in two separate physical systems having consistently similar relationships to each other are called analogous. One is then called the analog of the other. The electrical output of a transducer is an analog of the vibration input of the transducer as long as the transducer is not operated in the nonlinear (overloaded) range.

This is in contrast to a digital representation of the vibration signal, which is a sampled and quantisized signal consisting of a series of numbers, usually in binary notation.

11. Analog to Digital Conversion

The process of sampling an analog signal produces a series of numbers which is the digital representation of the same signal. The sampling frequency must be at least twice as high as the highest frequency present in the signal to prevent aliasing errors.

12. Angularity

The angle between two shaft center lines; this angle is the same at any point along either centerline. It is normally specified in rise/run.

13. Anti-Aliasing Filter

The low pass filter in the input circuitry of digital signal processing equipment such as FFT analyzers which eliminates all signal components higher in frequency than one-half the sampling frequency. See Aliasing.

14. Apodize, Apodization

To apodize is to remove or smooth a sharp discontinuity in a mathematical function, an electrical signal or a mechanical structure. An example would be to use a Hanning Window in the FFT analyzer to smooth the discontinuities at the beginning and end of the sample time record.

15. Asymmetrical Support

A rotor support system that does not provide uniform restraint in all radial directions. This is typical in industrial machinery where stiffness in one plane may be substantially different than stiffness in the perpendicular plane. Occurs in bearings by design, or from preloads such as gravity or misalignment.

16. Asynchronous/ Nonsynchronous

Frequencies in a vibration spectrum that exceed shaft turning speed (TS), but are not integer or harmonic multiples of TS. Also commonly refered to as non-synchronous.

17. Attitude Angle

The angle between the steady state preload through the bearing centerline, and a line drawn between the bearing center and the shaft centerline. (Applies to fluid film bearings).

18. Auto Correlation

Auto correlation is a time-domain function that is a measure of how much a signal shape, or waveform, resembles a delayed version of itself. It is closely related to the Cepstrum, q.v. The numerical value of auto correlation can vary between zero and one. A periodic signal, such as a sine wave has an auto correlation that is equal to one at zero time delay, zero at a time delay of one-half the period of the wave, and one at a time delay of one period; in other words, it is a sinusoidal waveform itself. Random noise has an auto correlation of one at zero delay, but is essentially zero at all other delays.

Auto correlation is sometimes used to extract periodic signals from noise. Certain dual-channel FFT analyzers are able to measure auto correlation.

19. Averaging

In performing spectrum analysis, regardless of how it is done, some form of time averaging must be done to accurately determine the level of the signal at each frequency. In vibration analysis, the most important type of averaging employed is linear spectrum averaging, where a series of individual spectra are added together and the sum is divided by the number of spectra.

Averaging is very important when performing spectrum analysis of any signal that changes with time, and this is usually the case with vibration signals of machinery. Linear averaging smoothes out the spectrum of the random noise in a spectrum making the discrete frequency components easier to see, but it does not actually reduce the noise level.

Another type of averaging that is important in machinery monitoring is time domain averaging, or time synchronous averaging, and it requires a tachometer connected to the trigger input of the analyzer to synchronize each "snapshot" of the signal to the running speed of the machine. Time domain averaging is very useful in reducing the random noise components in a spectrum, or in reducing the effect of other interfering signals such as components from another nearby machine.

See also Time Synchronous Averaging.

20. Axial

In the same direction as the shaft centerline.

21. Axial Float (or End Float)

Movement of one shaft along its centerline due to the freedom of movement permitted by a journal bearing or a sleeve bearing. This adjustment should be set before performing vertical or horizontal moves. The degree of axial float can be adjusted by the position of the stops, or whatever limits the motion.

22. Backlash

A condition where a rotor can rotate freely for a certain angular distance before encountering any resisting force. It may be measured in degrees. This term normally applies to couplings and gears.

23. Band Pass Filter

The frequency range over which a filter passes a signal within 3 dB of full strength. Outside the filter bandwidth, the signal is attenuated. The further outside, the greater the attenuation.

24. Bandwidth

The difference in frequency between the upper and lower cutoff frequencies of a bandpass filter or other device is called the bandwidth of the filter or device.

25. Baseplate

The surface to which the feet of a machine are attached.

26. Bearing

Primarily two types, rolling element and sleeve or plain bearing. Rolling element bearings consist of four parts: an inner race, an outer race, balls or rollers, and a cage to maintain the proper separarion of the rolling elements. A sleeve bearing is a cylinder of alloy metal surrounding the rotating shaft. Contact between the shaft and sleeve is prevented by a lubrication film.

27. Bearing Frequencies

Faults in any of the four bearing components will generate specific frequencies dependent upon the bearing geometry and rotating speed.

BPFO - Ball Pass Frequency, Outer Race

BPFI - Ball Pass Frequency, Inner Race

BSF - Ball Spin Frequency

FTF - Fundamental Train Frequency

28. Bearing Misalignment

A misalignment that results when the bearings supporting a shaft are not aligned with each other. The bearings may not be mounted in parallel planes, cocked relative to the shaft, or distorted due to foundation settling or thermal growth.

29. Bearing Nomenclature

Each bearing manufacturer has specific codes applied as prefixes and suffixes to their bearings. These codes inform the user of the construction, materials, clearances, and other factors used in the construction of the bearing. Consult the individual manufacturer's handbook for specific code meaning.

30. Beat Frequency

If two vibration components are quite close together in frequency and if they are present at the same time at the same place, they will combine in such a way that their sum will vary in level up and down at a rate equal to the difference in frequency between the two components. This phenomenon is known as beating, and its frequency is the beat frequency.

There is confusion in some areas between beating and amplitude modulation, which also can produce an undulating vibration level. Amplitude modulation is different from beating, and is caused by a high-frequency component being multiplied by a lower-frequency component and is thus a nonlinear effect, whereas beating is simply a linear addition of two components whose frequencies are close to one another.

31. Bins

In an FFT spectrum, the individual frequencies at which the amplitudes are calculated, commonly called "lines."

32. Binwidth

The binwidth equals the frequency span divided by the number of lines. Effective binwidth equals the binwidth times the window noise factor.

33. Bit

Short for binary digit. A number expressed in binary notation utilizes the digits 1 and 0, and these are called bits. Any number can be expressed with combinations of them.

34. Bode Plot

A plot of the frequency response function that includes log magnitude versus frequency plus phase versus frequency. For a single-degree of freedom, the magnitude is a maximum at the natural frequency and the phase shift is 90?. A type of spectrum plot that consists of a graph of amplitude vs frequency and a graph of phase vs frequency. In most vibration analysis work the phase spectrum is not important and is either ignored or not recorded. In two-channel vibration measurements, such as transfer functions and frequency response measurements used for modal analysis, phase is of vital importance.

The term is named after a man named Bode (pronounced Bo-day), who worked at the Bell Telephone Labs.

35. Bolt Bound

The situation whereby a machine cannot be moved in the desired direction because of mounting hole restrictions.

36. Bow

A shaft condition such that the geometric centerline of the shaft is not straight.

37. Buffer

A memory location in a computer or digital instrument which is set aside for temporarily storing digital information while it is waiting to be processed.

38. Bump Testing

A single channel approximation to a two channel impact test. This method works because the impacting force approximates an impulse and imparts broadband excitation over a limited frequency range. Since the Fourier Transform of the impulse response function is the frequency response function, it provides a good method of estimating the natural frequencies of the structure.

39. Calculated peak

Term used to describe the spectral overall RMS level multiplied by sqrt (2). Sometimes referred to as "derived peak" or "pseudo peak."

40. Cepstrum

The cepstrum is the forward Fourier transform of a spectrum. It is thus the spectrum of a spectrum, and has certain properties that make it useful in many types of signal analysis. One of its more powerful attributes is the fact that any periodicities, or repeated patterns, in a spectrum will be sensed as one or two specific components in the cepstrum. If a spectrum contains several sets of sidebands or harmonic series, they can be confusing because of overlap. But in the cepstrum, they will be separated in a way similar to the way the spectrum separates repetitive time patterns in the waveform.

Gearboxes and rolling element bearing vibrations lend themselves especially well to cepstrum analysis. The cepstrum is closely related to the auto correlation function.

41. Characteristic Equation

The mathematical equation whose solution defines the dynamic characteristics of the structure in terms of its natural frequencies, damping, and mode shapes. The mathematical formulation of the characteristic equation is called the Eigenvalue problem. The characteristic equation is obtained from the equations of motion for the structure.

42. Circle Fit

A single-degree of freedom curve fitting routine that tries to fit a mode to a circle (Nyquist plot of a single-degree of freedom system). The modal coefficient is determined by the diameter of the circle and the phase by its location relative to the imaginary axis.

For a real mode, it should be either completely above or completely below the imaginary axis.

43. Coefficient of Thermal Expansion

The constant value or factor of expansion of a material for a given increase in temperature, divided by the length of the material. This is different for each material.

44. Coherence

Coherence is a number between one and zero, and is a measure of the degree of linearity between two related signals, such as the input force of a structure related to the vibration response to that force. Coherence is thus a two-channel measurement, and does not apply to single-channel measurements of vibration signatures.

In a frequency response measurement of a mechanical structure, if the structure is linear, the coherence will be one, but if there is some nonlinearity in the structure or if there is noise in a measurement channel, the coherence will be less than one.

The dual-channel FFT analyzer is able to measure the coherence between the two channels, and it is a useful tool in determining good from noisy or meaningless data.

45. Coherence Function

Coherence is a function of frequency that measures amount of power in the response (output) that is caused by the power in the excitation (input). If it is 100% coherent, the value is 1.

46. Co-Incident

Another name for the real part of the frequency response function.

47. Cold Alignment

Machine condition in which alignment procedures are normally performed. Changes in off-line to on-line running conditions should be allowed for during this procedure so that the machine can "grow" into alignment during operation. Also known as static alignment or primary alignment.

48. Complex Modes

The points on a structure have varying phase relationships between them at a natural frequency. This is unlike a real mode where the phase between points is either 0? or 180?.

49. Compliance

Frequency response function of displacement/force. Also known as Dynamic Compliance.

50. Coulomb Damping

Nonlinear damping that is a result of rubbing, looseness, etc.

51. Coupling

Mechanical fixture for joining two shafts.

52. Critical Damping

The smallest amount of damping required to return a system to its equilibrium condition without oscillating.

53. Cross Correlation

Cross correlation is a measure of the similarity in two time domain signals. If the signals are identical, the cross correlation will be one, and if they are completely dissimilar, the cross correlation will be zero. Certain dual-channel FFT analyzers are able to measure cross correlation.

54. Damped Natural Frequency

The damped natural frequency is the frequency at which a damped system will oscillate in a free vibration situation.

55. Damping

Energy dissipation in an oscillating structure. For free vibration, that results in a decay in the amplitude of motion over time.

56. Damping Factor or Damping Ratio (z)

The ratio of actual damping in a system to its critical damping,

57. Degrees of Freedom

The number of coordinates or independent variables it takes to completely describe the location of a structure.

58. Detector

An electronic circuit that determines the amplitude level of a signal in accordance with certain rules. The simplest type of detector consists of a resistor and a capacitor, and it measures the average value of a fluctuating DC signal. A more complex but much more useful type of detector is an RMS detector. RMS detectors are used because they are proportional to the power or energy present in the signal or a vibration.

59. Deterministic

A type of signal whose spectrum consists of a collection of discrete components, as opposed to a random signal, whose spectrum is spread out or "smeared" in frequency. Some deterministic signals are periodic, and their spectra consist of harmonic series. Vibration signatures of machines are in general deterministic, containing one or more harmonic series, but they always have non-deterministic components, such as background noise.

60. Dial Indicator

Instrument used to measure amounts of motion, or displacement in thousandths of an inch (mils) increments.

61. Differentiation

In vibration analysis, differentiation is a mathematical operation that converts a displacement signature to a velocity signature, or a velocity signature to an acceleration signature. It is performed electronically on an analog signal or can be performed digitally on a spectrum. Differentiation is an inherently noisy operation, if performed on an analog signal, adding a significant amount of high frequency noise to the signal, and is generally not used very much in machinery vibration analysis. It is not inherently noisy if it is done digitally on the FFT spectrum. See also Integration, which is the inverse of differentiation.

62. Digital

Digital instrumentation consists of devices that convert analog signals into a series of numbers through a sampling process and an analog to digital converter. They then perform operations on the numbers to achieve such effects as equalization, data storage, data compression, frequency analysis, etc. This process in general is called digital signal processing. It is characterized by several advantages and disadvantages.

One advantage is that the converted signals can be manipulated, transformed and copied without introducing any added noise or distortion. The disadvantage is that the signal representation may not be truly representative of the original signal.

63. Discrete

With reference to a spectrum, discrete means consisting of separate distinct points, rather than continuous. An example of a discrete spectrum is a harmonic series. An FFT spectrum, which consists of information only at specific frequencies (the FFT lines), is actually discrete regardless of the input signal. For instance, the true spectrum of a transient is continuous, and the FFT of a transient appears continuous on the screen, but still only contains information at the frequencies of the FFT lines.

The input signal to an FFT analyzer is continuous, but the sampling process necessary to implement the FFT algorithm converts it into a discrete form, with information only at the specific sampled times.

64. Discrete Fourier Transform

The mathematical calculation that converts, or "transforms" a sampled and digitized waveform into a sampled spectrum. The fast Fourier transform, or FFT, is an algorithm that allows a computer to calculate the discrete Fourier transform very quickly. See also Fast Fourier Transform.

65. Dodd Bar

A secondary alignment method. Consists of two bars that are similar in configuration to reverse dial indicator bars. However these bars are not mounted on the shaft, they are mounted to the machine. Each bar is fitted with a proximity probe and it corresponds to a block on the other bar. As the machines move to their on-line condition the gap between the proximity probe and the metal block changes, which changes the voltage. The analyzer converts the voltage to a distance and from these distances, the alignment corrections can be calculated.

66. Domain

A domain is a set of coordinates in which a mathematical function resides. A waveform, for instance, has dimensions of amplitude and time, and it is said to exist in the time domain, while a spectrum has dimensions of amplitude and frequency, and is said to exist in the frequency domain.

67. Doweling

Permanently mounted pins in the baseplate, which are inserted into close tolerance holes in the machine's feet, used to bring machines back to the same aligned position.

68. Driving Point Measurement

A frequency response measurement where the excitation point and direction are the same as the response point and direction.

69. Dynamic Range

The ratio in dB between the highest signal level that can be tolerated without distortion and the broadband noise level measured in the absence of the signal.

70. Dynamic Stiffness

The frequency response function of force/displacement.

71. Eccentricity, Mechanical

The variation of the outer diameter of a shaft surface when referenced to the true geometric centerline of the shaft. Out-of- roundness. See also Runout.

72. Eccentricity Ratio

The vector difference between the bearing centerline and the average steady-state journal centerline. Applies to sleeve bearings not anti-friction bearings.

73. Eddy current probe

A non-contact electrical device that measures the displacement of one surface relative to the tip of the probe. Construction consists of an electrical coil of various lengths and diameters. This coil located in the tip of the probe is energized producing an electrical field around the tip of the probe. When a conductive surface is placed in the field and the distance from the probe is noted, variations in this gap can be termined by the variations in the voltage flow to the probe tip.

74. Effective Mass

The frequency response function of force/acceleration.

75. Eigenvalue

The roots of the characteristic equation.

76. Eigenvalue Problem

The mathematical formulation and solution of the characteristic equation is called the Eigenvalue problem.

77. Eigenvector

The mode shape vectors.

78. Engineering Units, EU

The units in which a measurement is made; for instance velocity may be expressed in millimeters per second, miles per hour, or furlongs per fortnight, depending on the use to which the data will be put. Modern instrumentation, such as FFT analyzers allow one to specify what the engineering units are and to apply conversion factors if needed.

79. Essinger Bars

A seconardy alignment method used to measure the difference between on-line and off-line running conditions. The method measures the change in distance and a change in angle between two tooling balls. One ball is fixed to the bearing and the other ball is fixed to a fixed reference point (usually the floor). The balls are connected by means of an inside micrometer with a resolution of at least 0.001." This should be set up for both sides of the bearing, so the readings can be taken simultaneously. And readings should be taken at every bearing. As the machine "grows" the distances betwen the balls and the angle between the inside micrometer and a fixed location (also usually the floor) will change. And these changes can be used to determine the changes in alignment.

80. Exponential (Response) Window

A special windowing function for minimizing leakage in lightly damped structures that is used in impact testing. In a lightly damped structure, oscillations may not die out within the sampled time data block, T, which results in leakage error. An exponential window adds damping to the time signal to force it to die out within the time T, thus minimizing leakage. The added damping is then removed mathematically after the signal is processed.

81. Face-Rim Method (or Rim-face method)

A method of shaft alignment where the indicators are mounted both radially and axially on one machine or the other, not both.

82. Fast Fourier Transform (FFT)

The FFT is an algorithm, or digital calculation routine, that efficiently calculates the discrete Fourier transform from the sampled time waveform. In other words it converts, or "transforms" a signal from the time domain into the frequency domain. See also DFT. The illustration shows the relation between the time record length, the time between samples, the frequency span f and the frequency resolution. The most important relation here is that the frequency resolution is inversely proportional to time record length. Therefore, high-resolution spectrum analysis of necessity takes a long time to collect the time record.

83. FFT Analyzer

The FFT analyzer is a device that uses the FFT algorithm to calculate a spectrum from a time domain signal, and is the most common type of spectrum analyzer available today. The FFT analyzer is a very useful device, and is available in a great variety of models with varying complexity. It is the heart of any machinery predictive maintenance program. See also Fast Fourier Transform.

84. Filter

A filter is an electrical circuit that allows signals in certain frequency ranges to pass through, and attenuates or blocks all other frequencies. There are many types of filters, such as low pass filters, high pass filters, and band pass filters. Examples of filters used in machinery monitoring instruments are low pass filters to reject high frequency noise and to prevent aliasing, and high pass filters to reject low frequency noise. Variable frequency band pass filters were used in the past to perform spectrum analysis, but they have been largely supplanted by the FFT analyzer.

85. Finite Element Analysis or Modeling

A computer-aided design technique for mathematically modeling a structure. Finite element modeling is used for structural analysis, heat transfer analysis, and modal analysis.

86. Fixed Machine

The machine whose position is not changed during shaft alignment. Compare with Shim Machine.

87. Flattop Window

The flattop window is a special window used in some FFT analyzers in addition to the more common Hanning window and rectangular window. The flattop window does not allow as fine a frequency resolution as the Hanning window, but it will accurately measure the amplitude level of a signal at any frequency, even if the frequency is between the lines of the FFT analysis. It is used in transducer calibration systems to increase amplitude accuracy.

88. Force Window

A special windowing function for minimizing noise in impact testing. Since the duration of the actual impact is usually very short relative to the overall digitized time sample, the frequency response function of the force signal can have a low signal to noise ratio. The force window does not alter the actual force pulse but minimizes the noise in the rest of the data block giving a much improved signal to noise ratio.

89. Forced Response Analysis (Forced Response Simulation)

Mathematically calculating the system response to an arbitrary forcing function using modal analysis data as the system model.

90. Forced Vibration

The oscillation of a system under the action of a forcing function.

91. Foundation

The surface to which the machine baseplate is mounted.

92. Fourier, Jean Baptiste

The famous many-talented French engineer, mathematician, and one time president of Egypt, who devised the Fourier series and Fourier Transform for the conversion of time functions into frequency functions and vice versa.

93. Fourier Transform

The mathematically rigorous operation which transforms from the time domain to the frequency domain and vice versa. See also Fast Fourier Transform.

94. Fourier Analysis

Fourier analysis is another term for spectrum analysis, although it generally refers to analysis using an FFT analyzer, q.v.

95. Frequency

The repetition rate of a periodic vibration, per unit of time, determined by taking the reciprocal of the period (T). Frequency is expressed in three ways: Hz (how many cycles per second); cpm (how many cycles per minute); and orders (how many cycles per shaft turning speed [TS]). Frequency is also the x-axis of the vibration spectrum; it identifies the source of the vibration.

Frequency is the reciprocal of time. If an event is periodic in time, i.e. if it repeats at a fixed time interval, then its frequency is one divided by the time interval. If a vibrating element takes one tenth of a second to complete one cycle and return to its starting point, then its frequency is defined to be 10 cycles per second, or 10 hertz (Hz). Although the SI standard unit of frequency is the Hz, when analyzing machinery vibration it is sometimes more convenient to express frequency in cycles per minute (cpm), which corresponds to rpm. Frequency in cpm is simply frequency in Hz times 60.

Another common frequency representation used in machinery monitoring is multiples of turning speed, or "orders." Frequency in orders is frequency in cpm divided by the turning speed of the machine. The second order is then the second harmonic of turning speed, etc. This is especially convenient if the machine is varying in speed, for the frequency representation on a spectrum will be the same regardless of speed. Two spectra from the same machine can therefore more easily be compared if they are both expressed in orders. Conversion of the frequency axis of a spectrum to orders is called "order normalization," and is done by vibration monitoring analyzers.

96. Frequency Domain

Vibration exists in time, and it is said to be in the "time domain." The representation of a vibration signal in the time domain is a "wave form," and this is what one would see if the signal were displayed on an oscilloscope. If the waveform is subjected to a spectrum analysis, the result is a plot of frequency vs amplitude, called a spectrum, and the spectrum is in the frequency domain.

The waveform is said to be transformed from the time domain to the frequency domain. Most detailed analysis of machinery vibration data is done in the frequency domain, but certain information is more easily interpreted in the time domain.

97. Frequency Response

The frequency response function, also called the FRF, is a characteristic of a system which has a measured response resulting from a known applied input. In the case of a mechanical structure, the frequency response is the spectrum of the vibration of the structure divided by the spectrum of the input force to the system.To measure the frequency response of a mechanical system, one must measure the spectra of both the input force to the system and the vibration response, and this is most easily done with a dual-channel FFT analyzer. Frequency response measurements are used extensively in modal analysis of mechanical systems.

The frequency response function is actually a three-dimensional quantity, consisting of amplitude vs. phase vs. frequency. Therefore a true plot of it requires three dimensions, and this is difficult to represent on paper. One way to do it is the so-called Bode plot, which consists of two curves, one of amplitude vs. frequency and one of phase vs. frequency. Another way to look at the frequency response function is to resolve the phase portion into two orthogonal components, one in-phase part (called the real part), and one part 90 degrees out of phase (called the "quadrature" or "imaginary" part). Sometimes these two phase parts are plotted against each other, and the result is the so-called Nyquist plot.

98. Frequency Response Function (FRF)

The output to input relationship of a structure. Mathematically, it is the Fourier transform of the output divided by the Fourier transform of the input. It is also the transfer function measured along the jz axis in the s-plane.

99. Frequency Response Matrix

For an N degree of freedom system, it is an N x N symmetrical matrix whose elements are the frequency response functions between the various points on the structure. Rows correspond to response points and columns to excitation points.

For example, H23 is the frequency response with excitation at point 3 and response at point 2. The matrix is redundant, that is, by knowing any row or column, the other elements of the matrix can be computed.

100. Fundamental Frequency

1. The spectrum of a periodic signal will consist of a fundamental component at the reciprocal of the period and possibly a series of harmonics of this frequency. The frequency is directly related to the phase-locked, rotational speed being measured and its amplitude may be low enough that it is difficult to see in the spectrum.

2. The spectrum of a periodic signal will consist of a fundamental component at the reciprocal of its period and a series of harmonics of this frequency. The fundamental is also called the "first harmonic." It is possible to have a periodic signal where the fundamental is so low in level that it cannot be seen, but the harmonics will still be spaced apart by the fundamental frequency.

101. Fundamental Train Frequency (FTF)

The rotation frequency or rate of the cage supporting the rolling elements in an anti-friction bearing. The FTF is always less than one-half shaft TS.

102. Generalized Coordinates

The minimum number of independent coordinates necessary to completely describe a systems position constitutes a set of generalized coordinates. For an N degree of freedom system, N generalized coordinates are required.

103. Hamming Window

Named after its originator, the Hamming window is a Hanning window sitting on top of a small rectangular pedestal. Its function is similar, but has its first sidelobes 42 dB down, whereas the Hanning window's first sidelobes are only 32 dB down. Thus the Hamming has better selectivity for large signals, but it suffers from the disadvantage that the rest of the sidelobes are higher, and in fact fall off slowly at 20 dB per octave like those of the rectangular window. The Hamming window had some advantage in the days when FFT analyzers only had 50 dB or so of dynamic range, but nowadays it is essentially obsolete.

104. Hanning Window

The Hanning window, also called "Hanning weighting," is a digital manipulation of the sampled signal in an FFT analyzer which forces the beginning and ending samples of the time record to zero amplitude. This compensates for an inherent error in the FFT algorithm which would cause the energy at specific frequencies to be spread out rather than well defined in frequency. The Hanning window causes a distortion of the wave form used by the analyzer to calculate the spectrum, and this results in the measured levels being too low. When processing continuous data, this effect is compensated for, but an error is introduced if the Hanning window is used for transient data.

105. Harmonic

A frequency that is an integer multiple of a given (subsynchronous, synchronous or nonsynchronous) frequency.

106. Harmonics

Harmonics, also called a harmonic series, are components of a spectrum which are integral multiples of the fundamental frequency. A harmonic series in a spectrum is the result of a periodic signal in the waveform. Harmonic series are very common in spectra of machinery vibration.

107. Hertz

The unit of frequency in the SI measurement system is the hertz, abbreviated Hz. One hertz is equal to one cycle per second. The name is in honor of Heinrich Hertz, an early German investigator of radio wave transmission.

108. High-Pass Filter

A filter that passes signal frequencies above a specific, or cutoff, frequency is called a high pass filter. They are used in instrumentation to eliminate low-frequency noise, and to separate alternating components from direct (DC) components in a signal.

109. Hysteresis

Non-uniqueness in the relationship between two variables as a parameter increases or decreases. Also called deadband, or the portion of the system's response where a change in input does not produce a change in output.

110. Hysteresis Damping (Hysteretic Damping, Structural Damping)

Energy losses within a structure that are caused by internal friction within the structure. These losses are independent of speed or frequency of oscillation but are proportional to the vibration amplitude squared.

111. Imaginary Part

A plot of the imaginary part of the frequency response function versus frequency. For a single-degree-of-freedom system, the magnitude is a maximum or minimum at the damped natural frequency.

112. Impact Testing

A method of measuring the frequency response function of a structure by hitting it with a calibrated hammer and measuring the system's response. The impact hammer is instumented with a load cell to measure the input force pulse while the response is typically measured using an accelerometer. The impact imparts a force pulse to the structure which excites it over a broad frequency range.

113. Impedance, mechanical

The mechanical impedance of a point on a structure is the ratio of the force applied to the point to the resulting velocity at the point. It is a measure of how much a structure resists motion when subjected to a given force, and it is the reciprocal of mobility. The mechanical impedance of a structure varies in a complicated way as frequency is varied. At resonance frequencies, the impedance will be low, meaning very little force can be applied at those frequencies. Mechanical impedance measurements of machine foundations are sometimes made to insure their suitability for the machine in question. For instance, it would not be good to have a foundation resonance near the turning speed of the machine.

114. Impulse Response

The response of a system to a unit impulse or Dirac's delta function. The Fourier transform of the impulse response is the frequency response function.

115. Inclinometer

A gravity device that measures angular position in degrees.

116 Induced Soft Foot

A type of soft foot that is caused by external forces (coupling, pipe strain, etc.) acting on a machine independent of the foot to baseplate connection.

117. Inertance

The frequency response function of acceleration/force. Also known as accelerance.

118. Integration

Integration is the mathematical operation which is the inverse of differentiation. In vibration analysis, integration will convert an acceleration signal into a velocity signal, or a velocity signal into a displacement signal. Integration can be done with excellent accuracy with an analog integrator in the time domain or can be done digitally in the frequency domain. For this reason an accelerometer is the transducer of choice because velocity and displacement can be so easily derived from its output. An analog integrator is actually a low pass filter with 6 dB of attenuation per octave. This is true of an analog integrator only above its low cutoff. And since the low cutoff cannot be zero, analog integrators have low-frequency limits, usually either 1 or 10 Hz.

119. Jackscrew (or Jackbolt)

A bolt or screw attached to the baseplate or foundation that is used to move or position the machine that is being moved.

120. Jack Shaft

A long shaft that is used as a spacer between two machines. Aso, a long turning shaft with several sheaves.

121. Lateral Location

The physical location of a rotor relative to the fixed, or non-rotating parts of the machine.

122. Leakage

In an FFT analyzer, the input signal is recorded in time blocks, called time records, and individual spectra are computed from each block of data. Because the input signal period is not synchronized with the duration of the time block, the signal will be truncated at the beginning and end of the block. This truncation causes an error in the calculation which effectively spreads out, or "smears" the spectrum in the frequency domain. This phenomenon is called leakage; the signal energy essentially "leaks" from a single FFT line to adjacent lines. Leakage reduces the accuracy of the measured levels of peaks in the spectrum, and reduces the effective frequency resolution of the analysis. Leakage is worst for continuous signals and rectangular window, and it is greatly reduced by use of the Hanning window, which forces the signal level to zero at the ends of the data block. See also Hanning.

123. Level

In common usage the level of a signal is its amplitude, but strictly speaking the term should be reserved for the amplitude expressed on a decibel scale relative to a reference value.

124. Line Spacing

In an FFT spectrum, the frequency difference between two adjacent bin centers or lines.

125. Line Spectrum

A line spectrum is a spectrum where the energy is concentrated at specific frequencies (lines or bins), as opposed to a continuous spectrum where the energy is smeared out over a band of frequencies. A deterministic signal will have a line spectrum, and a random signal will have a continuous spectrum. Spectra generated by machine vibration signatures are always a combination of these two types.

126. Low Pass Filter

A filter that passes signals with less than 3 dB attenuation up to its cutoff frequency, and attenuates the signal above that frequency. The attenuation slope is called the roll off, q.v. An anti-aliasing filter is an example of a low pass filter.

127. Machinery Train

Three or more machines that must be aligned to one another.

128. Mechanical Impedance

The frequency response function of force/velocity.

129. Micrometer, Outside

Tool used to measure thickness.

130. Milliradian

This is one thousanth of a radian. A radian is an angle whose subtended arc is equal to the radius at which the arc is measured. It amounts to about 57.3 degrees. There are 2p radians in a circle. A unit (normally metric) used to describe the angle of one machine centerline to the other. It is the equivalent to 1 mils/inch. It can also be expressed as rise/run. (1 unit =17.45 milliradians)

131. Mils

A unit of measure for displacement (thousandths of an inch). Usually measured in mils peak to peak, which represents total displacement.

141. Mils/Inch

A unit (normally English) used to describe the angle of one shaft centerline to the other. It is equivalent to milliradians. It can also be expressed as rise/run (1 unit = 17.45 mils/inch), as long as the rise is measured in mils and the run is measured in inches.

142. Mobility

The frequency response function of velocity/force.

143. Mobility

Mobility is the inverse of mechanical impedance. It is a measure of the ease with which a structure is able to move in response to an applied force, and varies it with frequency.The vibration measured at a point on a machine is the result of a vibratory force acting somewhere in the machine. The magnitude of the vibration is equal to the magnitude of the force times the mobility of the structure. From this it follows that the amplitude of the destructive forces acting on a machine are not determined directly by measuring its vibration if the mobility of the machine is not known. For this reason, it is a good idea to measure the mobility at the bearings of a machine in order to find out the levels of the forces acting on the bearings due to imbalance or misalignment.

144. Modal Analysis

The process of determining a set of generalized coordinates for a system such that the equations of motion are both inertially and elastically uncoupled. More commonly, it is a process of determining the natural frequencies, damping factors, and mode shapes for a structure. This is usually done either experimentally through frequency response testing or mathematically using finite element analysis.

145. Mode Shape

The relative position of all points on a structure at a given natural frequency.

146. Multiple-Degree-of-Freedom System (MDOF)

An N-degree-of-freedom system is a system whose position in space can be completely described by N coordinates or independent variables.

147. Natural Frequency

The frequency of oscillation of the free vibration of a system if no damping were present. For a single-degree-of-freedom system, the natural frequency where k is the spring constant and m is the mass.

148. Node

A point or line on a vibrating structure that remains stationary.

149. Noise

Any unwanted signal. Can be random or periodic.

150. Nonsynchronous, Asynchronous

Frequencies in a vibration spectrum that exceed shaft turning speed (TS), but are not integer or harmonic multiples of TS. See asynchronous.

151. Nyquist Frequency

Digital signal processing requires analog to digital (A to D) conversion of the input signal. The first step in A to D conversion is sampling of the instantaneous amplitudes of signal at specific times determined by the sampling rate. If the signal contains any information at frequencies above one-half the sampling frequency, the signal will not be sampled correctly, and the sampled version of the signal will contain spurious components. This is called aliasing. The theoretical maximum frequency that can be correctly sampled is equal to one-half the sampling rate, and is called the Nyquist frequency. In all digital signal processing systems, including FFT analyzers, the sampling rate is made to be significantly greater than twice the highest frequency present in the signal in order to be certain the aliasing will not occur.

152. Nyquist Plot

A plot of the real part versus the imaginary part of the frequency response function. For a single-degree-of-freedom system, the Nyquist plot is a circle. The Nyquist plot is representation of a frequency response function by graphing the "real" part versus the "imaginary" part. In the Nyquist plot, a resonance shows up as a circle, but there is no indication what its frequency is -- the Nyquist plot is like sighting down the frequency axis at the real and imaginary parts of the function.

153. Octave

An octave is a frequency interval having a ratio of two. It is called an octave from the music tradition where an octave spans eight notes of the scale. The second harmonic of a spectral component is one octave above the fundamental. In acoustical measurements, sound pressure level is often measured in octave bands, and the center frequencies of these bands are defined by the ISO. Vibration measurements are seldom expressed as octave band levels, but the US Navy has used 1/3 octave band analysis for vibration measurements on submarines for a long time.

154. Off-line to On-line Running Condition

Movement of the shaft center lines associated with (or due to) a change in pressures, temperatures and other forces between the static and operating condition.

155. Offset

Distance between rotational center lines at any given normal plane, usually measured at the coupling midpoint. Usually measured in mils in the US, and mm or microns in the rest of the world.

156. Optical Alignment

A secondary alignment method for determining on-line and off-line changes in alignment conditions. This method involves a scale of some type affixed to a machine such that a transit can be used to measure movement of the machine as it grows to its on-line position.

157. Order

An expression of frequency which relates a frequency (subsynchronous, synchronous or nonsynchronous) to shaft TS. It is calculated using the simple formula: Order=f/TS. In order analysis, the frequency axis of the spectrum is expressed in orders of shaft TS (i.e. peaks may be refered to as 1xTS, 2xTS or .43xTS or 6.77xTS).

158. Order Analysis

Order analysis is simply frequency analysis where the frequency axis of the spectrum is expressed in orders of rpm rather than in Hz or rpm.

159. Order Tracking

Order tracking is a special case of FFT analysis applied to variable-speed rotating machines where the sampling frequency of the analyzer is varied to be an exact multiple of the running speed of the machine while a series of spectra are recorded. The spectra are usually shown on top of one another on the page, and this is sometimes called a waterfall plot. In this way, the running speed and its harmonics will always occur at the same frequencies, or orders, in the spectrum regardless of the machine speed. Other vibration components not related to running speed, such as line frequency effects will not be synchronous with running speed, and will show up as curves on the waterfall plot. A tachometer pulse from the machine is needed to determine the FFT analyzer's sampling frequency. Some analyzers have the order tracking function built in, but others need an external frequency multiplier to derive the sampling frequency from the tachometer signal.

160. Overall RMS Level

A measure of the total RMS magnitude within a specified frequency range.

161. Overlap Processing

In the FFT analyzer, the time signal is stored in a buffer before being processed to form the spectrum. The FFT algorithm only processes the data when the time buffer is full, and after the widowing function, i.e. Hanning, is applied to it. This windowing causes data at the beginning and end of the time records to be represented at the wrong amplitude values, creating errors in the spectral amplitude levels. If two time buffers are used, and if the FFT algorithm is allowed to process the signal alternately from each buffer at a rate faster than the time it takes to fill the buffers, overlap processing is said to be the result. Overlap processing is desirable when using a Hanning Window because it ensures against loss of data for parts of the signal that occur near the beginning and end of the window. Most FFT-type data collectors use 50% overlap processing as a default. An overlap of 66.7% will completely correct for amplitude errors caused by the Hanning window.

162. Parameter Estimation

The process of evaluating and curve fitting frequency response functions in order to estimate modal parameters.

163. Peak

The maximum positive or negative dynamic excursion from zero (for an AC coupled signal) or from the offset level (for a DC coupled) of any time waveform. Sometimes referred to as "true peak" or "waveform peak."

164. Peak-to-peak

The amplitude difference between the most positive and most negative value in the time waveform.

165. Peak Pick

A parameter estimation technique where the peak value of the imaginary part of the frequency response function is used to estimate the mode shape value at that point. The phase is given by its sense (positive or negative). This method is also known as quad picking since the value is being picked off the imaginary or quadrature part of the frequency response function.

166. Peak Scaling, Peak-to-peak Scaling, RMS Scaling

Methods to display the amplitude axis of a spectrum.

167. Period

A signal that repeats the same pattern over time is called periodic, and the period is defined as the length of time encompassed by one cycle, or repetition. The period of a periodic waveform is the inverse of its fundamental frequency.

168. Periodic

A signal is periodic if it repeats the same pattern over time. The spectrum of a periodic signal always contains a series of harmonics.

169. Perpendicular

At right angles (90?) to a given line or plane.

170. Picket Fence Effect

The FFT spectrum is a discrete spectrum, containing information only at the specific frequencies that are decided upon by setting the FFT analyzer analysis parameters. The true spectrum of the signal being analyzed may have peaks at frequencies between the lines of the FFT spectrum, and the peaks in the FFT spectrum will not be at exactly the correct frequencies. This is called Resolution Bias Error, or the Picket Fence Effect. The name arises because looking at an FFT spectrum is something like looking at a mountain range through a picket fence.

By a process of interpolation, it is possible to increase the apparent resolution and amplitude accuracy of the FFT spectrum by a factor of ten.

171. Pipe Strain

Casing and flange distortion caused by improper pipe flange fit up.

172. Power Spectral Density

Power spectral density, or PSD, is a method of scaling the amplitude axis of spectra of random rather than deterministic signals. Because a random signal has energy spread out over a frequency band rather than having energy concentrated at specific frequencies, it is not meaningful to speak of its RMS value at any specific frequency. It only makes sense to consider its amplitude within a fixed frequency band, usually 1 Hz. PSD is defined in terms of amplitude squared per Hz, and is thus proportional to the power delivered by the signal in a one-Hz band.

173. Quadrature Response

Another name for the imaginary part of the frequency response function.

174. Quasi-Periodic

A quasi-periodic signal is a deterministic signal whose spectrum is not a harmonic series, but nevertheless exists at discrete frequencies. The vibration signal of a machine that has nonsynchronous components resembles a quasi-periodic signal. In most cases, a quasi-periodic signal actually is a signal containing two or more different periodic components.

175. Radial

Direction perpendicular to the shaft centerline.

176. Radial Position

The average location, relative to the radial bearing centerline, of the shaft's dynamic motion. Applies only to sleeve bearings.

177. Real Part

A plot of the real part of the frequency response function versus frequency. For a single degree of freedom, the magnitude is zero at the damped natural frequency.

178. Real or Normal Modes

In a real mode, all points on the structure reach a maximum or a minimum value at the same time and all pass through equilibrium at the same time.

179. Rectangular Window

In the FFT analyzer, the rectangular window is actually no window at all. It is also called rectangular weighting, or uniform weighting, and is used when the signal to be analyzed is a transient rather than a continuous signal. See also Hanning Window.

180. Repeatability

The consistency (or variation) of readings and results between consecutive sets of measurements. It has nothing to do with accuracy.

181. Residual Terms

Terms added to a curve fit algorithm to take into account the effects of modes outside the range being fitted. These terms consist of a mass term on the low frequency end and a stiffness term on the high.

182. Resolution

The smallest change or amount a measurement system can detect.

183. Resonance

When a forcing frequency is the same as a resonant frequency of the structure, the structure is said to be in resonance.

184. Resonant Frequency

The frequency of maximum amplification for a given damping ratio,z.

185. Response Spectrum

The frequency response function, also called the response spectrum, is a characteristic of a system that has a measured response resulting from a known applied input. In the case of a mechanical structure, the frequency response is the spectrum of the vibration of the structure divided by the spectrum of the input force to the system. To measure the frequency response of a mechanical system, one must measure the spectra of both the input force to the system and the vibration response, and this is most easily done with a dual-channel FFT analyzer. Frequency response measurements are used extensively in modal analysis of mechanical systems.The frequency response function is actually a three-dimensional quantity, consisting of amplitude vs. phase vs. frequency. Therefore a true plot of it requires three dimensions, and this is difficult to represent on paper. One way to do this is the so-called Bode plot, which consists of two curves, one of amplitude vs. frequency and one of phase vs. frequency. Another way to look at the frequency response function is to resolve the phase portion into two orthogonal components, one in-phase part (called the real part), and one part 90 degrees out of phase (called the "quadrature" or "imaginary" part). Sometimes these two phase parts are plotted against each other, and the result is the so-called Nyquist plot.

186. Reverse Indicator Method

Method for taking shaft alignment readings with indicators mounted radially at opposite ends of a spanned section (on each machine).

187. Rise/Run

For smaller angles, the ratio obtained when the change in offset between two center lines is divided by the distance along either centerline (between the points of offset measurement) . In effect, it is the slope of one line in a plane compared to another line in the same plane. Angularity is normally specified in mils/inch, or milliradians which is rise/run.

188. Roll Off, Rolloff

The attenuation of a high-pass or low-pass filter is called roll off. The term is mostly used for high frequency attenuation.

189. Roots

The roots of the characteristic equation are complex and have a real and imaginary part. The real part describes the damping (decay rate) of the system and the imaginary part describes the oscillations or damped natural frequency of the system.

190. Rotational Play

Looseness, usually in a coupling, where a rotor can rotate a given distance before the rotational play is out and the coupled shaft begins to rotate also.

191. Runout

A change in dial indicator position at the surface of the rotor during one rotation of the rotor, used to measure out-of-roundness or indicate a bent shaft. See also Eccentricity, Mechanical.

192. Sag

Deflection due to gravity acting on a cantilevered or otherwise supported object. Mechanical brackets that hold alignment tools always sag a certain amount. This sag must be corrected if the machine moves are to calculated correctly.

193. Secondary Alignment

The act of measuring off-line to on-line machinery movement.

194. Selectivity

Selectivity is a measure of the narrowness of a band pass filter. The greater the selectivity, the narrower, or more selective, the filter. The term is also used to describe the ability of a radio receiver to separate transmitting stations that are close together on the dial.

195. Sensor

Any device that translates the magnitude of one quantity into another quantity. Three of the most common transducers used in vibration measurements are accelerometer, velocity transducer, and eddy current probe.

196. Shim

A thin piece of material inserted between the machine feet and the baseplate used to produce precise vertical adjustments to the machine centerline. Shims are normally made of stainless steel, mild steel, or plastic. Shims come in various thicknesses from 1 mil to 125 mils.

197. Shim Machine

The machine whose position is changed during shaft alignment. Compare with Fixed Machine.

198. Sidebands

Sidebands are spectral components that are the result of amplitude or frequency modulation. The frequency spacing of the sidebands is equal to the modulating frequency, and this fact is used in diagnosing machine problems by examining sideband families in the vibration spectrum. For instance, a defective gear will exhibit sidebands spaced apart at the gear rpm around the gearmesh frequency.

199. Signal

In vibration analysis, a signal is an electric voltage or current which is analog of the vibration being measured.

200. Single-Degree-of-Freedom System (SDOF)

A system whose position in space can be completely described by one coordinate.

201. Soft Foot

A term used to describe any condition where tightening or loosening the bolt (s) of the machine feet distorts the machine frame.

202. Spacers

A generic term for any coupling that has 2 flex planes separated by a connecting shaft without bearings or other supports (between the flex points). Sometimes called an insert or spider.

203. Spectra

Spectra is the plural of spectrum.

204. Spectrum

The spectrum is the result of transforming a time domain signal to the frequency domain. It is the decomposition of a time signal into a collection of sine waves. The plural of spectrum is spectra. Spectrum analysis is the procedure of doing the transformation, and it is most commonly done with an FFT analyzer.

205. Spectrum Analyzer

A spectrum analyzer converts a signal from the time domain into the frequency domain, and the FFT analyzer is the most common type today, but there are many other types.

206. Spool Piece

Any piece of pipe or shafting that can be removed from a line of piping or shafting without disturbing or disassembling any other components. The name spool piece comes from the physical appearance of the piece, often a short cylinder with flanges the ends, which resembles a spool of string or thread.

207. Standard Deviation

If the instantaneous distances from an equilibrium position of a vibrating body are squared and averaged, the result is called the variance of the vibration. The square root of the variance is the standard deviation. It is also equal to the rms (root mean square) value.

208. Stationary Signal

A stationary signal is a signal whose average statistical properties over a time interval of interest are constant, and it may be deterministic or not. In general, the vibration signatures of rotating machines are stationary.

209. Structural Modification

Mathematically determining the effect of changing the mass, stiffness, or damping of a structure and determining its new modal parameters. A modal analysis provides, in essence, a mathematical model of the structure. This model can be manipulated to determine the effect of modifications to the structure. The modal model can be generated either experimentally or using a finite element program.

210. Sub Harmonic

Sub harmonics are synchronous components in a spectrum that are multiples of 1/2, 1/3, or 1/4 of the frequency of the primary fundamental. They are sometimes called "sub-synchronous" components. In the vibration spectrum of a rotating machine, there will normally be a component at the turning speed along with several harmonics of turning speed. If there is sufficient looseness in the machine so that some parts are rattling, the spectrum will usually contain sub harmonics. Harmonics of one-half turning speed are called "one-half order sub harmonics," etc.

211. Subsynchronous

Frequencies in a vibration spectrum that are lower than the fundamental frequency.

212. Synchronous

Synchronous literally means "at the same time," but in spectrum analysis, synchronous components are defined as spectral components that are integral multiples, or harmonics, of a fundamental frequency. They may in some cases exist as multiples of an integral fraction of the fundamental frequency, in which case they are called sub harmonics.

213. Synchronous Averaging

A type of signal averaging where successive records of the time waveform are averaged together. This is also know as time domain averaging. The important criterion is that the start of each time record must be triggered from a repetitive event in the signal, such as 1X rpm. The triggering assures that the phase of the waveform components that are synchronized with the trigger are the same in each record. Then in the averaging process, these in-phase components will add together while the rest of the signal components will gradually average out because of their random relative phases. The technique is excellent for extracting signals from noisy environments.

214. Thermal Growth

Movement of the shaft center lines associated with (or due to) a change in machinery temperature between the static and operating conditions.

215. Thermal Profile

A secondary alignment method used to measure thermal growth. This method is only used for calculating the vertical thermal growth of the shaft centerline due to a change in temperature. The shim plane, under the machine feet, serves as a benchmark. This technique is usually used for machines under 500 HP. The technique uses the linear expansion equation where: Expansion in mils (E) is equal to the average change in temperature, F? (T) multiplied by the vertical distance from the shim plane to the shaft centerline, in inches mutiplied by the coefficient of thermal expansion, in mils/inch F?. E =3D T X L X C This is to be calculated for both sides of the bearing. The number of temperture readings is not critical, but at least 4 is recommended. The average change in temperature is between the offline and online temperatures.

216. TIR

Total Indicator Runout. The total movement in mils of a dial indicator after a given rotation of a rotor.

217. Tolerance

The maximum permissible deviation from the specified quantity.

218. Transducer

Any device that translates the magnitude of one quantity into another quantity. Three of the most common transducers used in vibration measurements are accelerometer, velocity transducer, and eddy current probe.

219. Transfer Function

The output to input relationship of a structure. Mathematically it is the Laplace transform of the output divided by the Laplace transform of the input.

220. Transform

A transform is a mathematical operation that converts a function from one domain to another domain with no loss of information. For example, the Fourier transform converts a function of time into a function of frequency.

221. Transmissibility

The Fourier transform of the forced response of a structure measured at one location to the response at another location.

222. Tunable Filter

A filter whose cutoff frequencies are adjustable, either manually or under remote electrical control.

223. Uniform window

In the FFT analyzer, the uniform, or rectangular, window does not modify the signal amplitude at all. It is also called rectangular weighting, or uniform weighting, and is selected when the signal to be analyzed is a transient rather than a continuous signal. See also Hanning Window.

224. Undamped Natural Frequency

The same as the natural frequency of a structure.

225. Velocity Transducer

An electrical/mechanical transducer whose output is directly proportional to the velocity of the measured unit. A velocity transducer consists of a magnet suspended on a coil, surrounded by a conductive coil. Movement of the transducer induces movement in the suspended magnet. This movement inside the conductive coil generates an electrical current proportional to the velocity of the movement. A time waveform or a Fourier transform of the current will result in a velocity measurement. The signal can also be integrated to produce a displacement measurement.

226. Viscous Damping

Damping that is proportional to velocity. Viscous damping is used largely for system modeling since it is linear.

227. Waveform

The waveform is the shape of a time domain signal as seen on an oscilloscope screen. It is a visual representation or graph of the instantaneous value of the signal plotted against time. Inspection of the waveform can sometimes reveal information about the signal that the spectrum of the signal does not show. For instance a sharp spike or impulse and a randomly varying continuous signal can have spectra that look almost identical, while their waveforms are completely different. In machine vibration, spikes are usually caused by mechanical impacting, while random noise can be caused by the advanced stages of bearing degradation.

228. Wedge Shim

Technique where the use of several shims are used to fill the wedge-shaped gap of a bent foot. Each shim is inserted to a different depth so that the stair-stepped support is better built to support the entire foot.

229. Window

The FFT analyzer does not operate in a continuous manner, but is instead a batch processing device, taking samples of the time domain signal and transforming them into a frequency domain spectrum. The time interval during which the signal is sampled and recorded is called the window. In order to compensate for certain limitations of the FFT process, the time data in the window are often multiplied by a weighting curve, such as a Hanning or Flattop weighting. These weighting curves are also called the Hanning window and the Flattop window respectively.

Vita

Born in 1974, Bangkok, *Pongsupat Supasirisin* graduated from Suankularb Witayalai school in 1991. He earned Bachelor Degree in Electrical Engineering from Chulalongkorn University in 1995. He had been working at TPI Polene Public Company Limited as electrical engineer from 1995-1997 before resigned for further study in Engineering Management at the Regional Centre for Manufacturing System Engineering, the cooperation between Chulalongkorn University and University of Warwick.