LIST OF FIGURES

1.1 Tool health Monitoring as an element of CIM 2
1.2 Tool wear/Failure 3
1.3 Various methods of Tool wear monitoring 4

2.1 Generation of AE 15
2.2 Two types of AE 15
2.3 A Typical AE Signal 16
2.4 Possible sources of AE signals in metal cutting (Case of continuous chip formation) 18
2.5 Possible sources of AE signals in metal cutting (Case of discontinuous chip formation) 18
2.6 Major Sources of AE in Face milling 19
2.7 Layout of the Experimental setup 21
2.8 WIDAX 650 High shear milling cutter 26

AE Experimental results

1. Single insert
   i) En-2A (Medium speed, Low feed)
      2.9.1 Flank wear vs Cutting time
      2.9.2 Ring down count vs Flank wear
      2.9.3 Rise time vs Flank wear
      2.9.4 Rms voltage vs Flank wear
      2.9.5 Energy vs Flank wear
      2.9.6 Event duration vs Flank wear
      2.9.7 Mean Rise time vs Flank wear 29
   ii) En-2A (Low speed, High feed)
      2.9.8 Flank wear vs Cutting time
      2.9.9 Ring down count vs Flank wear
      2.9.10 Rise time vs Flank wear
      2.9.11 Rms voltage vs Flank wear
2.9.12 Energy vs Flank wear
2.9.13 Event duration vs Flank wear
2.9.14 Mean Rise time vs Flank wear

iii) En-8
2.9.15 Flank wear vs Cutting time
2.9.16 Ring down count vs Flank wear
2.9.17 Rise time vs Flank wear
2.9.18 Rms voltage vs Flank wear
2.9.19 Energy vs Flank wear
2.9.20 Event duration vs Flank wear
2.9.21 Mean Rise time vs Flank wear

iv) Grey cast iron
2.9.22 Flank wear vs Cutting time
2.9.23 Ring down count vs Flank wear
2.9.24 Rise time vs Flank wear
2.9.25 Rms voltage vs Flank wear
2.9.26 Energy vs Flank wear
2.9.27 Event duration vs Flank wear
2.9.28 Mean Rise time vs Flank wear

2. Two inserts (En-8)

i) Inserts placed adjacent
2.10.1 Avg. flank wear vs Cutting time
2.10.2 Flank wear vs Cutting time (for individual insert)
2.10.3 Ring down count vs Flank wear
2.10.4 Rise time vs Flank wear
2.10.5 Rms voltage vs Flank wear
2.10.6 Energy vs Flank wear
2.10.7 Event duration vs Flank wear
2.10.8 Mean Rise time vs Flank wear
ii) Inserts placed opposite

2.10.9 Avg. flank wear vs Cutting time
2.10.10 Flank wear vs Cutting time (for individual insert)
2.10.11 Ring down count vs Flank wear
2.10.12 Rise time vs Flank wear
2.10.13 Rms voltage vs Flank wear
2.10.14 Energy vs Flank wear
2.10.15 Event duration vs Flank wear
2.10.16 Mean Rise time vs Flank wear

3. Three inserts (En-8)

2.11.1 Avg. flank wear vs Cutting time
2.11.2 Flank wear vs Cutting time (for individual insert)
2.11.3 Ring down count vs Flank wear
2.11.4 Rise time vs Flank wear
2.11.5 Rms voltage vs Flank wear
2.11.6 Energy vs Flank wear
2.11.7 Event duration vs Flank wear
2.11.8 Mean Rise time vs Flank wear

Cumulative AE count

2.12.1 Cumulative count vs Flank wear (Single insert)
2.12.2 Cumulative count vs Avg. flank wear (Two insert)
2.12.1 Cumulative count vs Avg. flank wear (Three insert)

3.1 Surface Roughness Parameters

Surface Profile 1: En-8, One insert, C.speed 112 m/min, feed 0.25 mm/tooth
Surface Profile 2: Grey cast iron, One insert, C.speed 176 m/min, feed 0.22 mm/tooth
Surface Profile 3: En-8, Two insert (adjacent), C.speed 112 m/min, feed 0.13 mm/tooth
Surface Profile 4: En-8, Two insert (opposite), C.speed 112 m/min, feed 0.13 mm/tooth

3.2 Schematic Function Diagram of M4Pi
3.3 Experimental Setup for Surface Roughness Measurements

Surface Roughness Experimental Results

1. Single insert
   i) En-2A
      3.4.1 Flank wear vs Cutting time
      3.4.2 $R_a$ vs Flank wear
      3.4.3 $R_t$ or $R_q$ vs Flank wear
      3.4.4 $R_z$ vs Flank wear
      3.4.5 $R_{max}$ vs Flank wear
   ii) En-8
      3.4.6 Flank wear vs Cutting time
      3.4.7 $R_a$ vs Flank wear
      3.4.8 $R_t$ or $R_q$ vs Flank wear
      3.4.9 $R_z$ vs Flank wear
      3.4.10 $R_{max}$ vs Flank wear
   iii) Grey cast iron
      3.4.11 Flank wear vs Cutting time
      3.4.12 $R_a$ vs Flank wear
      3.4.13 $R_t$ or $R_q$ vs Flank wear
      3.4.14 $R_z$ vs Flank wear
      3.4.15 $R_{max}$ vs Flank wear

2. Two inserts (En-8)
   i) Inserts placed opposite
      3.5.1 Avg. flank wear vs Cutting time
      3.5.2 $R_a$ vs Avg. flank wear
      3.5.3 $R_t$ or $R_q$ vs Avg. flank wear
3.5.4 $R_z$ vs Avg. flank wear
3.5.5 $R_{\text{max}}$ vs Avg. flank wear

ii) Inserts placed adjacent
3.5.6 Avg. flank wear vs Cutting time
3.5.7 $R_a$ vs Avg. flank wear
3.5.8 $R_t$ or $R_q$ vs Avg. flank wear
3.5.9 $R_z$ vs Avg. flank wear
3.5.10 $R_{\text{max}}$ vs Avg. flank wear

3. Three inserts (En-8)
3.6.1 Avg. flank wear vs Cutting time
3.6.2 $R_a$ vs Avg. flank wear
3.6.3 $R_t$ or $R_q$ vs Avg. flank wear
3.6.4 $R_z$ vs Avg. flank wear
3.6.5 $R_{\text{max}}$ vs Avg. flank wear

4. Control Chart Evaluation (En-8)
3.7.1 Control chart for $R_a$
3.7.2 Control chart for $R_t$ or $R_q$
3.7.3 Control chart for $R_z$
3.7.4 Control chart for $R_{\text{max}}$

4.1 MLP architecture
4.2 MLP Training & Testing overview
4.3 Variation of Error with Epochs (12-24-1, En-8)
4.4 MLP Final architecture: 12-24-1 (En-8)
4.5 Network output vs Desired output (En-8)
4.6 MLP Final architecture: 36-10-1 (En-8)
4.7 MLP Final architecture: 12-12-3 (En-8)
4.8 Variation of Error with Epochs (12-20-1, Grey cast iron)
4.9 MLP Final architecture: 12-24-1 (Grey cast iron)
4.10 Network output vs Desired output (Grey cast iron) 83
4.11 Variation of Error with Epochs (12-12-1, En-2A) 83
4.12 MLP Final architecture: 12-12-1 (En-2A) 84
4.13 Network output vs Desired output (En-2A) 84
4.14 MLP Final architecture: 8-15-1 (En-8) 86
4.15 Variation of Error with Epochs (8-15-1, En-8) 86
4.16 MLP Final architecture: 6-10-1 (En-8) 87
4.17 Variation of Error with Epochs (6-10-1, En-8) 88
4.18 Network fusion Method 1 89
4.19 Network fusion Method 2 89

5.1 RBF architecture 95
5.2 Variation of Error with Epochs (12-66-1, En-8, Random selection of centers) 101
5.3 RBF: Final network architecture (12-66-1) Centers selected randomly 101
5.4 Variation of Error with Epochs (12-50-1, En-8, Batch fuzzy c-means) 107
5.5 RBF: Final network architecture (12-50-1) Centers initialized using batch fuzzy c-means 107
5.6 RBF: Final network architecture (12-60-1) Centers initialized using gradient descent approach 111

6.1 RAN architecture 117
6.2 RAN Training & Testing overview 119
6.3 Variation of Error as learning progresses (12-69-1, En-8) 120
6.4 Growth pattern (12-69-1, En-8) 120
6.5 RAN: Final architecture (12-69-1): En-8 data 121
6.6 Network output vs Desired output (12-69-1, En-8) 123
6.7 RAN: Final architecture (36-45-1): En-8 data 124
6.8 a Variation of Error as learning progresses (12-69-2, En-8) 126
   b Variation of Error as learning progresses (12-69-3, En-8) 126
6.9 Growth pattern (12-69-3, En-8) 126
6.10 a RAN: Final architecture (12-69-2): En-8 data 127
   b RAN: Final architecture (12-69-3): En-8 data 127
6.11 Variation of Error as learning progresses (12-91-1, Grey cast iron) 130
6.12 Growth pattern (12-91-1, Grey cast iron) 130
6.13 RAN: Final architecture (12-91-1): Grey cast iron data 130
6.14 Network output vs Desired output (12-91-1, Grey cast iron) 131
6.15 RAN: Final architecture (12-90-1): En-2A data 132
6.16 Network output vs Desired output (12-90-1, En-2A) 133

7.1 GCS network 137
7.2 Variation of Error with Epochs (12-25-1, En-8) 142
7.3 Insertion of RBF units with Epochs (12-25-1, En-8) 143
7.4 GCS: Final architecture (12-25-1) En-8 143
7.5 Variation of Error with Epochs (12-30-1, Grey cast iron) 145
7.6 Insertion of RBF units with Epochs (12-30-1, Grey cast iron) 145
7.7 GCS: Final architecture (12-30-1) Grey cast iron 145
7.8 Variation of Error with Epochs (12-35-1, En-2A) 146
7.9 Insertion of RBF units with Epochs (12-35-1, En-2A) 146
7.10 GCS: Final architecture (12-35-1) En-2A 147