

# Table of Contents

Foreword .....	viii
<b>1 Application Considerations .....</b>	<b>1</b>
<b>1.1 Sizing and Selection for Loads Types .....</b>	<b>1</b>
1.1.1 Variable Torque Loads .....	1
1.1.2 Constant Torque Loads .....	2
1.1.3 Combination Loads .....	3
1.1.4 High Inertia Loads .....	3
1.1.5 Overhauling Loads .....	3
1.1.6 Overspeed Condition.....	4
<b>1.2 Electrical Requirements .....</b>	<b>5</b>
1.2.1 Power Type .....	5
1.2.2 Motor Types and Number of Phases .....	5
1.2.3 Synchronous Motors .....	9
<b>1.3 Service Factor and Temperature Rise .....</b>	<b>10</b>
1.3.1 Service Factor and Margin.....	10
1.3.2 Insulation Systems and Temperature Rise.....	11
<b>1.4 Acceleration Requirements .....</b>	<b>13</b>
<b>1.5 Starting.....</b>	<b>14</b>
1.5.1 Motor Starters for AC Induction Motors .....	14
<b>1.6 Starting Requirements of Pumps.....</b>	<b>15</b>
1.6.1 Rotodynamic Pumps .....	15
1.6.2 Positive Displacement (PD) Pumps .....	17
1.6.3 NEMA Design Motors .....	18
1.6.4 Special Starting Requirements .....	19
<b>1.7 Types of Motor Starters.....</b>	<b>21</b>
1.7.1 Direct On-line (DOL) Starter .....	21
1.7.2 Solid-State Reduced Voltage Soft Starter (RVSS) .....	25
1.7.3 Wye-delta (a.k.a. Star-delta) Starter .....	28
1.7.4 Other Electromechanical Soft Starters .....	31
1.7.5 Variable Frequency Drive (VFD) .....	32
1.7.6 Comparison of starting technologies .....	34

<b>1.8</b>	<b>Duty Cycle .....</b>	<b>34</b>
<b>1.9</b>	<b>Motor Basics for Variable Speed Operation.....</b>	<b>36</b>
1.9.1	Motor Windings .....	37
1.9.2	Motor Bearings .....	38
<b>1.10</b>	<b>Couplings.....</b>	<b>39</b>
<b>1.11</b>	<b>Frame and Mounting.....</b>	<b>39</b>
1.11.1	Frame Designations.....	39
1.11.2	Horizontal .....	40
1.11.3	Vertical Mounting.....	42
1.11.4	Connection to Load .....	43
<b>1.12</b>	<b>Lubrication and Seals .....</b>	<b>45</b>
<b>1.13</b>	<b>Special Application Considerations .....</b>	<b>46</b>
1.13.1	Anti-Reversing Mechanism .....	46
1.13.2	Reed Critical Frequency (RCF) .....	46
<b>1.14</b>	<b>Environmental (Conditions as They Apply to Motors) ..</b>	<b>47</b>
1.14.1	Altitude .....	47
1.14.2	Ambient Temperature .....	48
<b>1.15</b>	<b>Motor Enclosures .....</b>	<b>48</b>
1.15.1	Ingress Protection (IP) Ratings .....	50
1.15.2	Enclosures for Hazardous Locations .....	50
<b>1.16</b>	<b>Industry and Regulatory Requirements .....</b>	<b>52</b>
<b>1.17</b>	<b>Efficiency labeling .....</b>	<b>53</b>
1.17.1	United States of America .....	53
1.17.2	Europe.....	55
1.17.3	Global Regulation .....	57
1.17.4	MEPS and Regulatory Markings .....	57
1.17.5	Increased Efficiency Considerations .....	58
<b>2</b>	<b>Installation Considerations .....</b>	<b>59</b>
<b>2.1</b>	<b>Electrical Installation.....</b>	<b>59</b>
2.1.1	Power Quality .....	59
2.1.2	Power Factor Correction Capacitors .....	61
<b>2.2</b>	<b>Installation Protective Devices.....</b>	<b>61</b>
2.2.1	Motor Starters, Overload Relays, and Fuses .....	61
2.2.2	Lightning and Surge Protection .....	61

2.2.3	Current Transformers – Differential Motor Protection . . . . .	63
<b>2.3</b>	<b>Local Codes . . . . .</b>	<b>63</b>
<b>2.4</b>	<b>Installation with VFD . . . . .</b>	<b>63</b>
2.4.1	Grounding of Motor . . . . .	63
2.4.2	VFD Input Power Cable . . . . .	64
2.4.3	Motor Cables . . . . .	65
<b>2.5</b>	<b>Mechanical Installation . . . . .</b>	<b>69</b>
2.5.1	Spacing . . . . .	69
2.5.2	Coupling Requirements . . . . .	70
2.5.3	Mounting and Alignment . . . . .	71
2.5.4	Bases and Foundations . . . . .	73
2.5.5	Vibration . . . . .	73
<b>2.6</b>	<b>Lifting Considerations . . . . .</b>	<b>74</b>
<b>2.7</b>	<b>Non-use/storage . . . . .</b>	<b>75</b>
<b>2.8</b>	<b>Startup and Commissioning . . . . .</b>	<b>75</b>
2.8.1	Electrical Connection . . . . .	75
2.8.2	Motor Direction of Rotation Test . . . . .	75
2.8.3	Reversing Rotation . . . . .	76
<b>3</b>	<b>Maintenance (AC Motors Only) . . . . .</b>	<b>77</b>
<b>3.1</b>	<b>Caution and Overview . . . . .</b>	<b>77</b>
3.1.1	Caution . . . . .	77
3.1.2	Overview Maintenance and Troubleshooting . . . . .	78
3.1.3	Tools and Meters . . . . .	78
<b>3.2</b>	<b>General Statement of Motor Lubrication Importance . . . . .</b>	<b>78</b>
<b>3.3</b>	<b>Proper Lubrication . . . . .</b>	<b>79</b>
<b>3.4</b>	<b>Over Lube . . . . .</b>	<b>79</b>
3.4.1	Grease . . . . .	79
3.4.2	Oil Lubrication . . . . .	79
<b>3.5</b>	<b>Under Lubrication . . . . .</b>	<b>79</b>
3.5.1	Grease . . . . .	79
3.5.2	Oil Lubrication . . . . .	80
<b>3.6</b>	<b>Relubrication Interval Recommendations (STLE) . . . . .</b>	<b>80</b>
3.6.1	Mixing Lube Types . . . . .	81
3.6.2	Oil Condition . . . . .	81

<b>3.7</b>	<b>Motor Alignment . . . . .</b>	<b>82</b>
<b>3.8</b>	<b>Couplings. . . . .</b>	<b>84</b>
<b>3.9</b>	<b>Enclosure. . . . .</b>	<b>84</b>
3.9.1	Visual Inspection . . . . .	85
3.9.2	Fan Inspection . . . . .	85
<b>3.10</b>	<b>Electrical Maintenance . . . . .</b>	<b>86</b>
3.10.1	Insulation Testing. . . . .	86
<b>3.11</b>	<b>Electrical Connections (Exterior to Frame) . . . . .</b>	<b>87</b>
3.11.1	Check Terminal Connections . . . . .	87
3.11.2	Maintaining Contactors and Across the Line Starters . . . . .	88
<b>3.12</b>	<b>Protective Devices. . . . .</b>	<b>90</b>
<b>3.13</b>	<b>Lubrication Sight Gauges. . . . .</b>	<b>90</b>
<b>3.14</b>	<b>Condition Monitoring . . . . .</b>	<b>90</b>
<b>3.15</b>	<b>Storage. . . . .</b>	<b>90</b>
3.15.1	Storage Area . . . . .	90
3.15.2	Coatings . . . . .	91
3.15.3	Shaft Rotation . . . . .	91
3.15.4	Motor Insulation. . . . .	91
3.15.5	Grease-lubricated Bearings. . . . .	91
3.15.6	Oil-lubricated Bearings . . . . .	91
3.15.7	Start-up After Storage . . . . .	92
<b>3.16</b>	<b>Maintenance When Connected to V-belt or Other Speed/Torque Controls . . . . .</b>	<b>92</b>
<b>3.17</b>	<b>Standby Motors . . . . .</b>	<b>93</b>
<b>3.18</b>	<b>Final Reminder. . . . .</b>	<b>93</b>
<b>4</b>	<b>Troubleshooting . . . . .</b>	<b>95</b>
<b>4.1</b>	<b>Major Failure Modes . . . . .</b>	<b>95</b>
4.1.1	Bearing . . . . .	95
4.1.2	Winding . . . . .	111
<b>4.2</b>	<b>Vibration. . . . .</b>	<b>117</b>
4.2.1	Causes . . . . .	117
4.2.2	Vibration Inspection. . . . .	117
<b>4.3</b>	<b>Temperature. . . . .</b>	<b>119</b>
4.3.1	Airflow . . . . .	119

4.3.2	Filters . . . . .	120
4.3.3	Verify Fan Integrity . . . . .	120
4.3.4	Cooling Fluid Temperature . . . . .	120
<b>4.4</b>	<b>Electrical . . . . .</b>	<b>120</b>
4.4.1	Terminal Connections . . . . .	120
4.4.2	Insulation Integrity . . . . .	121
4.4.3	Turn-To-Turn Winding Failure . . . . .	121
4.4.4	Phase-To-Phase Winding Failure . . . . .	121
4.4.5	Turn-To-Ground Winding Failure . . . . .	122
4.4.6	Single-phased Winding . . . . .	122
4.4.7	Accessory Devices . . . . .	123
<b>4.5</b>	<b>Misalignment . . . . .</b>	<b>124</b>
<b>4.6</b>	<b>Power Quality . . . . .</b>	<b>124</b>
<b>4.7</b>	<b>Motor and Variable Speed Drive (VSD) . . . . .</b>	<b>124</b>
4.7.1	Windings . . . . .	124
4.7.2	Bearings . . . . .	125
<b>4.8</b>	<b>Overloading . . . . .</b>	<b>126</b>
<b>4.9</b>	<b>Application Specific . . . . .</b>	<b>127</b>
<b>4.10</b>	<b>Lubrication . . . . .</b>	<b>131</b>