

# Table of Contents

Foreword .....	xi
Acknowledgements .....	xii
About the Hydraulic Institute .....	xiv
About Pump Systems Matter .....	xv

## Chapter • One

### **Introduction, 1**

1.1 Objective .....	1
1.2 Guideline Parameters .....	2
1.3 Reliability and MTBR Programs .....	2

## Chapter Two

### **Definitions, 5**

## Chapter Three

### **Establishing Reliability Objectives and Life Expectation, 13**

3.1 Introduction .....	13
3.2 Product Life .....	14
3.2.1 Stakeholders and Equipment Specification .....	14
3.2.2 Criticality of Service .....	15
3.2.3 Simplistic Design Life .....	16
3.2.4 Pump Stationary Element Design .....	18
3.2.5 Pump Wetted Impeller Casing and Liner Components .....	19
3.2.6 Shaft and Bearing Rotating Assembly Components .....	19
3.2.7 Bearing Housing and Electric Motor Seals .....	26
3.2.8 Pump Wet End Sealing .....	27
3.2.9 Electric Motor Drivers .....	29
3.2.10 Actual Equipment Life .....	36

## Chapter Four

### **Fundamentals of Reliability, 39**

4.1 Reliability-centered Maintenance .....	39
4.2 The General Bathtub Curve .....	39
4.3 Potential Failure Curve .....	40

4.4	RCM Techniques . . . . .	41
4.5	Planned versus Unplanned Maintenance. . . . .	41
4.6	RCM - Asset Criticality . . . . .	41
4.7	Condition Monitoring . . . . .	42
4.8	Monitoring Devices. . . . .	42
4.9	Vibration . . . . .	43
4.10	Reliability Improvement Project Selection Criteria . . . . .	43
4.11	When MTBR (Data Collection and Analysis) Should be Used in Improving Reliability . . . . .	45

## Chapter Five

### **Quantifying Reliability (Data Collection and Reporting), 47**

5.1	Introduction. . . . .	47
5.2	First Steps . . . . .	47
5.3	Collecting Installation, Event Dates, and Failure Information. . . . .	48
5.4	Reporting and Analyzing . . . . .	50
5.5	Quantifying Reliability by Calculating MTBR . . . . .	50
5.5.1	Calculating MTBR . . . . .	50
5.5.2	MTBR Example . . . . .	53
5.5.3	Calculating Rolling Average MTBR . . . . .	55
5.5.4	Rolling Average MTBR Example . . . . .	55
5.5.5	Expected Life . . . . .	55
5.5.6	Repair Rate . . . . .	56
5.6	Reliability: A Technical Definition . . . . .	56
5.7	Reliability Example . . . . .	56
5.8	Availability . . . . .	56
5.9	Average Cost per Repair . . . . .	57
5.10	Annual Repair Cost per Installed Horsepower . . . . .	57
5.11	Installed Cost per Horsepower per Machinery Type . . . . .	57
5.12	Material Multiplier . . . . .	57
5.13	Reporting Considerations. . . . .	57

## Chapter Six

### **Improving Reliability, 61**

6.1	Achieving Improved Reliability – Best Practices for Optimal Performance .....	61
6.2	Design Review and In-plant Operation .....	62
6.3	Process/Operational Factors .....	63
6.3.1	Net Positive Suction Head (NPSH) and Allowable Operating Region (AOR) .....	63
6.3.2	Allowable Nozzle Loads .....	66
6.3.3	Intake Design Considerations .....	68
6.3.4	Pump Piping .....	70
6.4	Specification- and Maintenance-related Issues .....	71
6.4.1	Materials of Construction .....	71
6.4.2	Pump Bearings and Bearing Housings .....	73
6.4.3	Bearing Housing Seals and Lubricants .....	75
6.4.4	Mechanical Seals .....	77
6.4.5	Compression Packing .....	87
6.4.6	Drivers .....	90
6.4.7	Gearboxes and Gearing .....	92
6.4.8	Coupling Components .....	92
6.4.9	Foundations and Baseplates .....	95

## Chapter Seven

### **Summary, 97**

#### Appendix A

### **MTBR Survey for Mechanical Seal Life, 101**

#### Appendix B

### **Troubleshooting Problems and Finding Possible Causes, 105**

#### Appendix C

### **Evaluating the Cost–Benefit of Enhancing Pump Reliability through MTBR, 113**

C.1	Introduction .....	113
C.2	Key Factors .....	113
C.3	Financial Payback Assessment .....	114

C.4 Case History Example . . . . .	118
C.4.1 Case 1: Corn Mash Slurry Pump . . . . .	118

#### Appendix D

### **Service Criticality Application Requirements and Specification Recommendations, 121**

#### Appendix E

### **Summary Steps in Setting Up a Reliability Improvement Program, 125**

#### Appendix F

### **Product Expectation Guide, 127**

#### Appendix G

### **Bibliography, 145**

#### Appendix H

### **Index, 149**

#### List of Figures

3.1 Plant shareholders with their different interests . . . . .	14
3.2 Simplistic life expectation diagram . . . . .	17
3.3 Normal hydraulic and other loads on a pump rotating assembly . . . . .	20
3.4 Multiple speed performance curve showing head and power variation . . . . .	21
3.5 Example of calculated bearing life for different heads and flows . . . . .	23
3.6 Example calculated shaft deflection for different specific gravities, heads, and flows . . . . .	24
3.7 Pump speed reliability/life impact . . . . .	25
3.8 Open - drip-proof motor . . . . .	31
3.9 Open - weather-protected type I motor . . . . .	32
3.10 Open - weather-protected type II motor . . . . .	32
3.11 Totally enclosed nonventilated motor . . . . .	33
3.12 Totally enclosed air over motor . . . . .	33

---

3.13	Totally enclosed fan-cooled motor . . . . .	34
3.14	Totally enclosed pipe (tube) ventilated motor . . . . .	34
3.15	Totally enclosed air-air-cooled motor . . . . .	35
3.16	Totally enclosed water-air-cooled motor . . . . .	36
4.1	RCM general bathtub curve . . . . .	40
4.2	Potential failure curve . . . . .	40
4.3	Best potential MTBR improvement paybacks . . . . .	45
5.1	Data fields example . . . . .	49
5.2	Rolling average MTBR . . . . .	52
5.3	Failure type examples . . . . .	53
5.4	Targeted application summarizing report . . . . .	54
5.5	Data interpretation and extrapolation . . . . .	59
5.6	Data trends and interpretation over time . . . . .	59
6.1	Reliability issues relative to BEP . . . . .	64
6.2	Simple pump system . . . . .	65
6.3	System changes affect AOR . . . . .	65
6.4	NPSH available versus NPSH required in different systems . . . . .	67
6.5	Pump piping nozzle loads . . . . .	68
6.6	Example of an asymmetrical suction location . . . . .	69
6.7	Undesirable effect of an elbow mounted directly on suction flange . . . . .	70
6.8	Section of a severely corroded impeller . . . . .	72
6.9	Relative effect of contamination by water . . . . .	74
6.10	Visual appearance of lubricant when water is present . . . . .	77
6.11	Possible seal leakage points . . . . .	78
6.12	Silicon carbide – no magnification . . . . .	81
6.13	Silicon carbide – 50x magnification . . . . .	82
6.14	Contact of shaft with inside diameter of gland plate . . . . .	83
6.15	Erosion of seal components . . . . .	84
6.16	Deep grooving of mating ring . . . . .	84
6.17	Leaching of reaction-bonded silicon carbide . . . . .	86
6.18	Cross section of seal face . . . . .	86
B.1	Observed MTBR deficiency . . . . .	106
C.1	Sample payback analysis model . . . . .	117

LIST OF TABLES

3.1 Service criticality for consideration of backup, monitoring, maintenance, spares availability, and reliability program inclusion. . . . . 15

3.2 Design life factors . . . . . 18

3.3 Ingress protection code . . . . . 26

3.4 Nominal PV limits for nonlubricating liquids. . . . . 28

3.5 Motor enclosures and degrees of protection . . . . . 30

5.1 Example data. . . . . 51

6.1 Oil contamination factor  $\eta_c$  . . . . . 75

B.1 Observed centrifugal pump deficiencies and causes. . . . . 107

B.2 Key to source of centrifugal pump problems (Table B.1). . . . . 109