

Table of contents	pg
1. Introduction	21
2. Breakdowns	27
2.1. Maintenance practice and reasons for malfunctions	29
2.2. Sources of the excitations	33
2.2.1. Malfunctions due to the hydraulics	33
2.2.1.1. Cavitation	37
2.2.1.2. Corrosion	51
2.2.1.3. Abrasion	59
2.2.1.4. Inlet conditions of the pump, causes of the malfunction of the pump	67
2.2.1.5. Hydraulic stability of the pump and its influence on piping vibrations	83
2.2.1.6. Operating range of centrifugal pumps	95
2.2.1.7. Interference between the impeller (z_2) and diffuser (z_3) vanes on the optimal combination of the number of vanes	99
2.2.1.8. Noise emission from centrifugal pumps	105
2.2.2. Auxiliary mechanical elements	115
2.2.2.1. Radial and axial bearings	115
2.2.2.2. Dynamic shaft seals and stationary O-rings	131
2.2.2.3. Couplings	145
2.2.2.4. Forces and moments resulting from piping	153
2.2.2.5. Base-plate vibration	163
2.2.3. Malfunctions due to shaft vibrations	169
2.2.3.1. Hydraulic unbalance	169
2.2.3.2. Mechanical unbalance	171
2.2.3.3. Interaction forces created in narrow gaps	173
2.2.3.4. The vibration of impeller shrouds	185
2.2.3.5. Transients in thermal power plants	189
3. Measuring the operating behavior of an existing pump in the system	195
3.1. Monitoring	197
3.2. Monitoring the vibrations of a pump	201
3.3. Measuring vibrations	209
4. Diagnosis and early-failure detection based on measurements in the plant under operating conditions	217

5. Guidelines for improvements and eliminating the sources of malfunction or damage with centrifugal pumps	231
5.1. Proposed improvements related to hydraulic performance	233
5.1.1. Cavitation	233
5.1.2. Recommendations with regard to corrosion	243
5.1.3. Abrasion	251
5.1.4. Inlet flow conditions	259
5.1.5. Unstable pump characteristics	277
5.1.6. Recommendations for avoiding the malfunction of a pump operating below its recommended range of operation	301
5.1.7. Recommendations for the reduction of noise emissions for centrifugal pumps	309
5.1.8. Optimal choice of combination impeller – number of guide vanes and excitation due to the interaction of the impeller outlet/diffuser	315
5.1.9. Recommendations in order to prevent damage to the impeller shrouds due to vibrations	325
5.2. Proposed improvements and recommendations for different auxiliary mechanical elements	331
5.2.1. Proposed improvements and recommendations for radial and axial bearings	331
5.2.2. Recommendations to avoid the malfunction of the shaft and the static seals	349
5.2.3. Recommendations to avoid malfunctions of the shaft couplings	357
5.2.4. Recommendations to avoid malfunctions of single- and multi-stage centrifugal pumps due to unbalanced forces, causing excitations at the rpm of the centrifugal pumps	361
5.2.5. Recommendations for reducing the effects of the interaction forces on the malfunctions of multi-stage pumps	367
5.2.6. Recommendations for the modification and design of the geometry of the base-plate	375
5.2.7. Recommendations for improvements in connection with the transient conditions in thermal power plants and HPI plants influenced by temperature changes in order to eliminate any malfunctions of the pump	385
5.2.8. Recommendations for the forces and moments on pump nozzles	395
6. Literature	403