## Contents

## Nomenclature

1	Introduction			1		
	1.1	Motivation and goals				
	feed water pump installed in RWE Niederaussem Power sta-					
		tion unit K - A short introduction				
		1.2.1	Hydraulic design- Operational parameters	4		
		1.2.2	Design details	5		
<b>2</b>	State of the Art - Condition monitoring and diagnosis					
	2.1	Condi	tion based maintenance: VDI guidelines	9		
	2.2	Condi	tion monitoring and diagnostic systems in power plants	11		
		2.2.1	Tasks and scope of condition monitoring and diagnostic			
			systems in power plants	12		
		2.2.2	On-line and off-line approaches	13		
		2.2.3	Choice of condition monitoring approaches	13		
	2.3	Optim	al start up and shut down process in power plants $\ldots$ .	15		
3	Sim	ulation	n of boiler feed water pump: Evaluation of hydraulic			
	and thermo-mechanical behavior 10					
	3.1	Nume	rical methods	17		
		3.1.1	Mathematical model	17		
		3.1.2	Discretization method	17		
			3.1.2.1 FDM- Finite difference method	17		
			3.1.2.2 FVM- Finite volume method	18		

## CONTENTS

			3.1.2.3 FEM- Finite element method	18	
		3.1.3	Numerical grid	19	
		3.1.4	Solution method	19	
		3.1.5	Convergence criteria	19	
	3.2	Numer	rical simulation of boiler feed water pump	20	
		3.2.1	3D-CAD modeling	20	
		3.2.2	Fluid and solid domain extraction	20	
		3.2.3	Mesh generation	21	
		3.2.4	Approach for coupled FEM-CFD simulations	22	
	3.3	Simula	ation of outer barrel casing of boiler feed pump and its veri-		
		ficatio	n by analytical solution	23	
	3.4	Simula	ations of single stage of boiler feed pump	28	
	3.5	Simula	ations of whole boiler feed pump	34	
	3.6	Valida	tion of temperature simulations by comparison with temper-		
		atures	measured by thermal elements installed on boiler feed water		
		pump		35	
	3.7	B.7 Deformation of impeller			
	3.8	8 Deformation of casing		37	
		3.8.1	Deformation of casing: symmetrical temperature distribution	37	
		3.8.2	Deformation of casing: unsymmetrical temperature distri-		
			bution	40	
	3.9	Equiva	alent(von-Mises) stress distribution in casing and impeller .	40	
4	Wal	l temp	perature difference calculation	<b>42</b>	
	4.1	Calcul	lation of the wall temperature difference	42	
		4.1.1	Inverse heat conduction problem and verification by a sim-		
			ple test case	44	
		4.1.2	Direct heat conduction problem	48	
	4.2	WADA	AR - Wall temperature difference calculation program	50	
		4.2.1	WADAR: Results	51	
		4.2.2	Verification of WADAR by comparison with analytical and		
			ANSYS solutions	53	

5	Life	time	consumption evaluation	<b>56</b>	
	5.1	Exhaustion by Creep		57	
	5.2	.2 Exhaustion by Fatigue		58	
	5.3	LIMPRO - LIfe Monitoring PROgram		61	
		5.3.1	Verification of LIMPRO by comparison of simulation re-		
			sults with an example given in European standard EN-		
			12952-3	62	
		5.3.2	LIMPRO(LIfe Monitoring PROgram): Results	63	
	5.4	Softwa	are chain: WADAR + LIMPRO	64	
6	Condition monitoring, diagnostic and controlling tool				
	6.1	Selecti	on of the optimal monitoring positions on the pump $\ldots$ .	69	
	6.2	Simpli	fied model of the pump's thermal and mechanical behavior	72	
	6.3	.3 Calculation of temperature distribution and stresses from t			
		history	y of outer surface temperature measurements at critical mon-		
		itoring positions		73	
		6.3.1	1-layer model of hollow cylinder	73	
		6.3.2	2-layers model of hollow cylinder	75	
		6.3.3	N-layers model of hollow cylinder: State space representa-		
			tion of thermal behavior of hollow cylinder and its verifica-		
			tion by ANSYS calculations	77	
		6.3.4	N-layers model of multi-material hollow cylinder: State		
			space representation	84	
	6.4	Mecha	nical stress and strain due to operation pressure	85	
	6.5	Mecha	nical stress and strain due to the rotation of rotor	86	
		6.5.1	Calculation of the centrifugal stress and strain $\ldots$ .	86	
		6.5.2	Pure shear deformation in blades	89	
		6.5.3	Verification of the calculation by ANSYS calculations	90	
	6.6	Calculation and monitoring of life time consumption			
	6.7	Calculation and monitoring of small gaps			
	6.8	Determination of allowable stress limits and free amount of stress 94			
	6.9	Determination of allowable temperature transients			
	6.10	Scheme of condition monitoring, diagnostic and controlling tool . 9			

## CONTENTS

	6.11 Condition monitoring, diagnostic and controlling scheme in MATLAB-			•	
	Sin	nuli	nk		96
	6.1	1.1	Input signals		96
	6.1	1.2	Results from condition monitoring, diagnostic and control-		
			ling tool $\ldots$		96
7	Summa	iry		1	04
References			1	06	