



CALCULATION

NOP-CC-3002-01 Rev. 00

INITIATING DOCUMENT (S) CRRRA 03-05065-14	CALCULATION NO. EA-254	<input checked="" type="checkbox"/> VENDOR CALC SUMMARY
TITLE/SUBJECT: Emergency Service Water System Pump Shaft Coupling Failure Analysis		

<input type="checkbox"/> BV1	<input type="checkbox"/> BV2	<input type="checkbox"/> DB	<input checked="" type="checkbox"/> PY
Category	<input checked="" type="checkbox"/> Active	<input type="checkbox"/> Historical	<input type="checkbox"/> Study
Classification	<input checked="" type="checkbox"/> Safety-Related/Augmented Quality	<input type="checkbox"/> Nonsafety-Related	
Open Assumptions?	<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No	If Yes, Enter CR Tracking Number	N/A
System Number:	P45		
Asset Number:	1P45-C001A		
Commitments:	None		
(Perry Only)	Calculation Type:	Referenced In Atlas?	<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No
		Referenced In USAR Validation Database	<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No

Computer Program(S)

Program Name	Version / Revision	Category	Status	Description
ANSYS	6.1	(vendor)	(vendor)	General Finite Element Analysis Program
P.C. Crack	3.1 98348	(vendor)	(vendor)	Crack Modeling program
Excel	(vendor)	(vendor)	(vendor)	Microsoft

Revision Record

Rev.	Affected Pages	Originator/Date	Reviewer/Date	Design Verifier/Date	Approver/Date
0	All	See vendor calculations	11/7/03 <i>[Signature]</i> 4/7/03	See vendor calculations	12/13/03 <i>[Signature]</i>
Description of Change: New Calc.					
Describe where the calculation has been evaluated for 10CFR50.59 applicability. See Supporting Docs R03-01672.					
Description of Change:					
Describe where the calculation has been evaluated for 10CFR50.59 applicability.					
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INITIATING DOCUMENT (S)

CRRRA 03-05065-14

CALCULATION NO.

EA-254

 VENDOR CALC SUMMARY

TITLE/SUBJECT:

Emergency Service Water System Pump Shaft Coupling Failure Analysis

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Reference 11 Corrosion and Fatigue in Fe-Ni-Cr alloys by Markus Speidel	25 pages
Reference 13 Atlas Fatigue Curves ASM	3 pages
Reference 16 Stress Concentration Factors by R. E. Peterson	4 pages
TOTAL NUMBER OF PAGES IN CALCULATION (COVERSHEETS + BODY + ATTACHMENTS)	108 Pages
SUPPORTING DOCUMENTS (<i>For Records Copy Only</i>)	
DESIGN VERIFICATION RECORD	N/A Pages
CALCULATION REVIEW CHECKLIST	2 Pages

NOP-CC-3002-01 Rev. 00

INITIATING DOCUMENT (S)
CRRA 03-05065-14CALCULATION NO.
EA-254 [X] VENDOR CALC SUMMARY

TITLE/SUBJECT:

Emergency Service Water System Pump Shaft Coupling Failure Analysis

Attachment 1

10CFR50.59 DOCUMENTATION

DESIGN INTERFACE SUMMARY

DESIGN INTERFACE EVALUATIONS

OTHER

Structural Integrity letter dated Nov. 17, 2003 Subject: Crack Growth Periods

11 Pages

2 Pages

2 Pages

N/A Pages

3 pages

EXTERNAL MEDIA? (MICROFICHE, ETC.) (IF YES, PROVIDE LIST IN BODY OF CALCULATION)

 YES NO

CALCULATION

NOP-CC-3002-01 Rev. 00

INITIATING DOCUMENT (S)

CRRA 03-05065-14

CALCULATION NO.

EA-254

 [X] VENDOR CALC SUMMARY

TITLE/SUBJECT:

Emergency Service Water System Pump Shaft Coupling Failure Analysis

OBJECTIVE OR PURPOSE:

The purpose of this calculation is to capture Structural Integrity calculations concerning the failure analysis of the 1P45-C001A pump shaft coupling.

SCOPE OF CALCULATION/REVISION:

The scope of this calculation includes a stress analysis of the pump shaft coupling and fracture analysis of the coupling performed by a vendor, Structural Integrity and Associates. Their vendor calculation numbers are PERY-03Q-301 and 302 respectively.

SUMMARY OF RESULTS/CONCLUSIONS:

The stress analysis was performed for two configurations. CR 03-05056 investigation identified that the pump shaft had failed and subsequent evaluation found the shaft coupling sleeves were not installed correctly. The shaft coupling sleeves were installed in such a way that the key, that is approximately four inches in length and lies axially between shaft and coupling sleeve was only $\frac{3}{4}$ engaged along its approximate 4 inch length. The results of the stress analysis indicate that the off centered coupling would experience an increase in peak stress at the key edge in the hoop direction of approximately 35.4 %. It was concluded that the higher hoop stress, the susceptible material, and the corrosive environment all contributed to stress corrosion cracking and the resulting failure of the coupling.

The fracture mechanics calculation establishes the fracture toughness of the material at approximately $50ksi\sqrt{in}$, develops an expression for stress intensity as a function of crack depth in the coupling sleeve, and establishes a likely crack growth rate based on industry data. From a graph of stress intensity verses crack depth, the model indicates that for a miss-installed coupling sleeve, a crack depth of 0.05 inches (for the full length of the coupling) results in failure. Fatigue is also addressed in the fracture mechanics evaluation. It is demonstrated that fatigue is not a likely failure mode based on the low number of starts experienced at the time of failure. The stress corrosion cracking growth rate supports the root cause failure mode of stress corrosion cracking.

LIMITATIONS OR RESTRICTIONS ON CALCULATION APPLICABILITY:

No limitations result from this calculation. This calculation simply addresses the existing design and the observed failure.

IMPACT ON OUTPUT DOCUMENTS:

No direct changes result from this calculation. However, the Design Engineer responsible for procuring new pumps and parts has been made aware of the results of this calculation. Additional corrective actions associated with the CR have been written to address both immediate and long term procurement requirements.



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NOP-CC-3002-01 Rev. 00

INITIATING DOCUMENT (S) CRRA 03-05065-14	CALCULATION NO. EA-254	<input type="checkbox"/> VENDOR CALC SUMMARY
TITLE/SUBJECT: Emergency Service Water System Pump Shaft Coupling Failure Analysis		

DOCUMENT INDEX

DIN No.	Document Number/Title	Revision, Edition, Date	Reference	Input	Output
1	Valve pump drawing 22 -0125-0000	2	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
2	Pace Energy Coupling Field Dimensions	N/A Attached to Reviewers' Comments	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
3	Pump Seismic Report McDonald Engineering Report No. 454 "Seismic analysis of Vertical Pump"	7/20/82	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
4	Addendum 1 Pump Seismic Report McDonald Engineering Report No. 454	4/3/84	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
5	Pump Shaft Field Dimensions	NA Attached to reviewers comments	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

NOP-CC-3002-01 Rev. 00

CALCULATION NO.:

EA-254

TITLE / SUBJECT:

Emergency Service Water System Pump Shaft Coupling Failure Analysis

ANALYSIS METHODOLOGY

See individual calculation. For stress analysis see Attachment 1 and for fracture analysis see Attachment 2.

ASSUMPTIONS

None

ACCEPTANCE CRITERIA

There is no acceptance criteria for this calculation. The objective is to perform a failure analysis of the coupling sleeve that supports the observed failure documented in CR 03-05065.

COMPUTATION

See Attachments

RESULTS

See cover sheet or individual calculation attachment

CONCLUSIONS

See cover sheet or individual calculation attachment

Document/Activity Evaluated: EA-254

Rev. 0

PROGRAMS and PROCEDURES INTERFACES

Required	DIRC Section	Topic	Prepare DIE and forward to:	DIE No.
<input type="checkbox"/>	N/A	Maintenance Procedures	Maintenance Support	01
<input type="checkbox"/>	N/A	Operations Procedures	Operations Procedures	02
<input type="checkbox"/>	N/A	Systems Programs & Procedures	Responsible System Engineer	03

DESIGN INTERFACES

Potential Interface Evaluated using DIRC (NOP-CC-2004-03) Rev:

<input type="checkbox"/>	1.0	ALARA	BOP Element, DES	
<input type="checkbox"/>	2.0	Fire Protection/Safe Shutdown	Applied Engineering Analysis Element, DES	
<input type="checkbox"/>	3.0	Equipment Qualification (3.1 – 3.10)	I&C Element, DES	
<input type="checkbox"/>	3.0	Equipment Qualification (3.5, 3.7, 3.11)	Structural/Mechanical Unit, DES	
<input type="checkbox"/>	3.0	Equipment Qualification (3.12)	BOP Element, DES	
<input type="checkbox"/>	4.0	Human Factors	I&C Element, DES	
<input type="checkbox"/>	5.0	Plant Security System	Electrical Power Element, DES	
<input type="checkbox"/>	6.0	Seismic	Structural/Mechanical Unit, DES	
<input type="checkbox"/>	7.0	Pipe Rupture	Applied Engineering Analysis Element, DES	
<input type="checkbox"/>	8.0	Internal Missile Hazards	Applied Engineering Analysis Element, DES	
<input type="checkbox"/>	9.0	NSSS Design Basis	NSSS Element, DES	
<input type="checkbox"/>	10.0	Containment Vessel and Drywell Isolation	Applied Engineering Analysis Element, DES	
<input type="checkbox"/>	11.0	Materials Compatibility/Chemical Control (11.1 – 11.10)	BOP Element, DES	
<input type="checkbox"/>	11.0	Materials Compatibility/Chemical Control (11.11 – 11.13)	Applied Engineering Analysis Element, DES	
<input type="checkbox"/>	12.0	Control Room Habitability	Applied Engineering Analysis Element, DES	
<input type="checkbox"/>	13.0	Mechanical Systems	Mechanical Unit, DES	
<input type="checkbox"/>	14.0	Penetrations	Structural/Mechanical Unit, DES	
<input type="checkbox"/>	15.0	Miscellaneous Structural Considerations	Structural/Mechanical Unit, DES	
<input type="checkbox"/>	16.0	Heavy Loads	Structural/Mechanical Unit, DES	
<input type="checkbox"/>	17.0	Electrical Systems	Electrical Power Element, DES	
<input type="checkbox"/>	18.0	Instrumentation and Controls	I&C Element, DES	
<input type="checkbox"/>	19.0	Simulator	Simulator Element, PES	
<input type="checkbox"/>	20.0	In-Service Inspection (ISI)	ISI/IST Element, PES	
<input type="checkbox"/>	21.0	Piping and Pipe Supports	Structural/Mechanical Unit, DES	
<input type="checkbox"/>	22.0	Hydrogen Control	Applied Engineering Analysis Element, DES	
<input type="checkbox"/>	23.0	Lubricants	BOP Element, DES	
<input type="checkbox"/>	24.0	Probabilistic Safety Assessment	PSA Element, DES	
<input type="checkbox"/>	25.0	Plant Characteristic Parameters	Reactor Engineering, Nuclear Fuels	
<input type="checkbox"/>	26.0	Motor Operated Valves (26.1 – 26.6)	Components & Material Unit, PES	
<input type="checkbox"/>	26.0	Motor Operated Valves (26.1 - 26.3)	Electrical Power Element, DES	
<input type="checkbox"/>	26.0	Motor Operated Valves (26.4 and 26.5)	Structural/Mechanical Unit, DES	
<input type="checkbox"/>	26.0	Motor Operated Valves (26.7 and 26.8)	Applied Engineering Analysis Element, DES	
<input type="checkbox"/>	26.0	Motor Operated Valves (26.9)	BOP Element, DES	
<input type="checkbox"/>	27.0	Plant Computers/Software	Plant Computer Support Unit, PES	
<input type="checkbox"/>	28.0	Maintenance Rule, 10CFR 50.65	Maintenance Rule Element, PES	
<input type="checkbox"/>	29.0	Piping & Equipment	Structural/Mechanical Unit, DES	
<input type="checkbox"/>	30.0	Predictive Maintenance	Predictive Maintenance Element, PES	
<input type="checkbox"/>	30.0	Predictive Maintenance (30.8)	BOP Element, DES	
<input type="checkbox"/>	31.0	Operations Impact	Plant Operations Section	
<input type="checkbox"/>	32.0	Maintenance Engineering	Maintenance Support Unit	
<input type="checkbox"/>	33.0	Component Engineering	Component Engineering Unit, PES	
<input type="checkbox"/>	Other:			
<input type="checkbox"/>	Other:			

See Attached Comments

Comments: No DIES are recommended. This calculation does not change design output documents. An ECP is necessary to change drawings and will receive the necessary interfaces. Therefore no procedure changes are necessary for this calculation. Plant maintenance procedures are being updated through corrective actions associated with CR 03-05065. The system Engineer will also be interfaced through the ECP process as well as operations if needed. Therefore, no interfaces are judged necessary at this time.

Prepared by:	(Print Name and Sign)	Supervisor Concurrence (Print and Sign Name)	Date
C. Flensburg	<i>C. Flensburg</i>	<i>Lori McGuire</i>	11/10/03
			12/13/03



November 17, 2003
SIR-03-152
GAM-03-004

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Mr. Walter Cory Flensburg
First Energy Corporation
Perry Nuclear Power Plant
10 N. Center Road
Perry, OH 44081-9514

Subject: Perry Pump Shaft Coupling

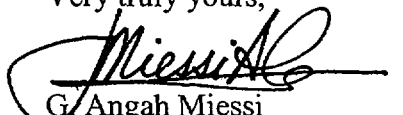
Dear Cory:

Structural Integrity Associates (SI) is providing herein a summary of the study performed to evaluate possible crack propagation mechanisms that could have caused crack growth in the shaft coupling while the pump shaft was idle.

The results of the study presented on the following pages, indicate that the potential crack growth mechanisms considered are not likely to have contributed to any significant crack propagation when the pump was not operating.

Please do not hesitate to call if you require any additional information.

Very truly yours,


G. Angah Miessi
Senior Consulting Engineer

ml
Attachment
cc: PERY-03Q

PERRY PUMP SHAFT COUPLING STUDY

POSSIBLE ALTERNATE CRACK PROPAGATION MECHANISMS ACTING DURING PUMP IDLE TIME

- **RESIDUAL STRESSES**

During pump standby conditions, in the absence of operational stresses, residual stresses, if present in the coupling, could potentially promote crack extension during pump idle conditions. Potential sources of residual stresses have been considered.

Assuming the coupling is fabricated from previously cold rolled, heat-treated material, the coupling stock material is expected to be free of residual stresses before machining. Any residual stresses associated with the cold fabrication would be removed by subsequent thermal relaxation associated with the tempering process.

Residual stresses associated with the machining process could be another source of residual stresses in the as-installed shaft coupling. A review of open literature has resulted in the conclusion that machining-related residual stresses are expected to be locally as high as yield level. While these levels of residual stress are sufficient to drive crack extension, the depth of the machining-cold work-induced residual stresses is limited to a “few mils”. Even aggressive, severe surface machining effects are attenuated within 10 to 12 mils beneath the machined surface.

It is concluded that residual stresses associated with machining processes, would not promote crack extension during pump standby conditions. This is further verified by the absence of surface cold work related cracking in a second, non-failed, coupling that had experience environmental and operational loading conditions similar to the coupling that failed.

- **OXIDE WEDGING**

During pump standby conditions, in the absence of operational stresses, the effects of “oxide wedging”, if present in the coupling, could potentially promote crack extension during pump idle conditions. The potential effects the hypothesized mechanism of “oxide wedging” has been considered.

The concept of crack extension by “oxide-wedging” involves the formation of the tensile stress field at the tip of an active existing crack of sufficient level to promote crack growth. The wedging action is produced by the formation of solid corrosion products within the crack cavity where the volume of the oxide is greater than the metal consumed by the formation of the crack cavity. The result of the wedging action promotes a mechanical tearing at the yielding crack tip, and may contribute to crack extension.

Review of open literature [Ref. Pickering, Beck, and Fontana – 1962; Hudak, and Page – 1983; and Cheng, and Potter - 1973] results in the conclusion that the mechanism of “oxide wedging” operates on a micro scale, and represents a localized residual stress condition with magnitude on

the order of approximately 20% to 30% of the applied stress intensities. The experimentally determined correlations of crack growth under cyclic or steady state applied loads, includes the empirical effects of oxide wedging. Further, the contribution from oxide wedging generally becomes increasing important as crack size decreases, thereby suggesting that it would be most significant during crack initiation and early growth of small cracks. Conversely, the contribution to crack growth (under applied loading) by oxide wedging becomes less important for pre-existing, established cracks.

It is concluded that the mechanism of “oxide wedging”, as a stand-alone mechanism would not promote crack extension during pump standby conditions.

- **HYDROGEN EMBRITTLEMENT**

Hardness levels above RC 40 are required for this mechanism to be a significant contributor. The Perry shaft coupling 416 S/S material was found to have measured hardness levels not exceeding RC 30. Hydrogen embrittlement is not considered to be viable contributor to crack extension during pump standby conditions.

CONCLUSION

Responding to the question whether IGSCC crack propagation would be evident during pump standby or just during pump operation, three potential IGSCC initiation/propagation contributors were explored, and found to be insignificant contributors to crack propagation during pump standby.

Residual stresses associated with the initial fabrication methods would have a maximum expected depth of 6 to 8 mils. Only insignificant near-surface crack extension could be attributed to this effect.

Oxide wedging as a potential mechanism of crack extension is likewise judged to be insignificant. Likewise, hydrogen embrittlement is not considered to be a viable mechanism of crack extension during standby conditions.

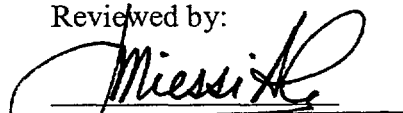
It is also noted that another pump coupling, with operational time and environment similar to the failed coupling had no evidence of incipient crack initiation or propagation due to the considered mechanisms.

It is therefore concluded that no detectable crack propagation occurs during pump standby conditions. The IGSCC initiation and propagation resulting in the failure of the coupling happened fully during pump operation, without detectable contribution during pump standby conditions.

Prepared by:


Daniel Delwiche, PhD

Reviewed by:


G. Angah Miessi

CALCULATION REVIEW CHECKLIST

NOP-CC-2001-04 Rev. 01

QUESTION	NA	Yes	No	COMMENTS	RESOLUTION
REFERENCES					
1. Does the stated objective/purpose clearly describe why the calculation is being performed?		x			
2. Are applicable codes, standards, design/licensing basis documents, etc., including edition and addenda where appropriate clearly identified?		x		References included	N/A
3. Do the references reflect the appropriate revision?		x			
INPUTS					
4. Are design inputs clearly identified and their source documents referenced, including revision level as appropriate?		x		Vendor calc provides sketch with critical dimensions	
5. Are the design inputs relevant, current, consistent with design/licensing bases and directly applicable to the purpose of the calculation, including appropriate tolerances and ranges/modes of operation?		x			
6. Are all design inputs retrievable? If not, have they been added as attachments?		x			
7. Are preliminary or conceptual inputs clearly identified for later confirmation as open assumptions?	x				
ASSUMPTIONS					
8. Have the assumptions necessary to perform the analysis been adequately documented?		x			
9. Is suitable justification provided for all assumptions (except those based upon recognized engineering practice, physical constants or elementary scientific principles)?		x			
10. Are all assumptions for the calculation reasonable and consistent with design/licensing bases?		x			
11. Have all open assumptions needing later confirmation been clearly identified on the Calculation cover sheet, including when the open assumption needs to be closed?	x				
12. Has a Condition Report been issued for open assumptions if required?	x				
13. Have engineering judgments been used?		x			
14. Are engineering judgments reasonable and adequately documented?		x			
METHOD OF ANALYSIS					
15. Is the method used appropriate considering the purpose and type of calculation?		x			
16. Is the method in accordance with applicable codes, standards, and design/licensing bases?		x			
IDENTIFICATION OF COMPUTER CODES (Ref: NOP-SS-1001)					
17. Have the versions of the computer codes employed in the design analysis been certified for this application?		x		Vendor programs used ANSYS and PC Crack, Excel	
18. Are codes properly identified along with source, inputs and outputs?		x			
19. Is the code suitable for the analysis being performed?		x			
20. Does the computer model, that has been created, adequately reflect actual (or to be modified) plant conditions (e.g., dimensional accuracy, type of model/code options used, time steps, etc.)?		x			
21. Is the computer output reasonable when compared to inputs and what was expected?		x			
COMPUTATIONS					
22. Are the equations used consistent with recognized engineering practice and design/licensing bases?		x			
23. Is justification provided for any equations not in common use?		x			
24. Is the justification reasonable?		x			
25. Have adjustment factors, uncertainties, empirical correlations, etc., used in the analysis been correctly applied?		x			
26. Is the result presented with proper units and tolerance?		x			
27. Has proper consideration been given to results that may be overly sensitive to very small changes in input?		x			

CALCULATION REVIEW CHECKLIST

NOP-CC-2001-04 Rev. 01

QUESTION	NA	Yes	No	COMMENTS	RESOLUTION
CONCLUSIONS					
28. Is the magnitude of the result reasonable when compared to inputs?		x			
29. Is the direction of trends reasonable?		x			
30. Are stated conclusions justifiable based on the calculation results?		x			
31. Are all pages sequentially numbered and marked with a valid calculation number?		x			
32. Is all information legible and reproducible?		x			
33. Have all changes in the documentation been initialed (or signed) and dated by the author of the change and all required reviewers?		x			
34. Have all calculation results stayed within existing design/licensing basis parameters?		x			
35. If the response to Question 34 is NO, has Licensing been notified as appropriate? (i.e. UFSAR or Tech Spec Change Request has been initiated).	x				
36. Does the calculation meet its purpose/objective?		x			
37. Has the calculation vendor used all applicable design information/requirements provided?		x			
38. Did the calculation vendor determine if the calculation was referenced in design basis documents and/or databases?	x				
39. Did the Preparer determine if the calculation was used as a reference in the UFSAR?		x			
40. If the calculation is used as a reference in the UFSAR, is a change to the UFSAR required or an update to the UFSAR Validation Database, if applicable, required?	x				
41. If the answer to Question 40 is YES, have the appropriate documents been initiated?	x				
42. Is the calculation acceptable for use?					
43. What checking method was used to review the calculation? Check all that apply.		x			
• spot check for math		x			
• complete check for math					
• comparison with tests					
• check by alternate method					
• comparison with previous calculation					

CALCULATION REVIEW CHECKLIST

NOP-CC-2001-04 Rev. 01

REV. 0

UNIT 1

QUESTION	NA	Yes	No	COMMENTS	RESOLUTION
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Review Summary: In addition to the above the following have been completed also:

NOP CC-3002 Rev. 0, Section 4.7.4 Owner Acceptance

1. Calc No. Obtained from Admin; EA-254
2. Prepare Calculation Cover sheet; Complete
3. Prepare Calculation review checklist; Complete
4. Indicate how No answers were resolved; None identified
5. Include Checklist as supporting documents to Calculation; Complete
6. Information required by Section 4.7.2; final calculation includes inputs , references, and methodology used to perform the calculation, summary of results of the calculation, list of assumptions, limitations, follow up on assumptions, and a copy of the vendors Design Verification Record. Discrepancies with inputs have been resolved. Inputs sent electronically have been rechecked during the analysis phase. The vendor has redrawn the coupling and dimensions were re-verified. Transmittal documents are attached to this Owner's Acceptance. 10CFR50.59 has been included in supporting documents.
7. Complete DIS per NOP CC 2004. DIS with supporting documents. Complete
8. Issue DIEs; Note corrective action issued per CR 03-05065 to revise procurement documents and pump drawings.
9. Revise Design Basis per NEI – 801. Design basis, engineered spare parts list or Design basis will be changed through the ECP process when drawings are updated.
10. No calculations provided input to this calculation and no output was provided to calculations from this calculation.
11. Calculation coversheet completed.
12. DIS is contained in the Supporting documents.
13. Print the name of the vendor who originated the calculation in the originator block of the calculation.
14. Print name, sign, and date

Attachment 1 to this Calculation Review Checklist contains the design inputs transmitted to the vendor as well as question and answers during calculation development.

<input type="checkbox"/> Technical Review		<input checked="" type="checkbox"/> Owner's Acceptance Review (Required for calculations prepared by a vendor)	
Reviewer (Print and Sign Name)	Date	Owner Acceptance Reviewer: (Print and Sign Name) C. Flensburg <i>C. Flensburg</i> 11/7/03	Date 11/7/03
		Approver: (Print and Sign Name) Lori M'Guire <i>Lori M'Guire</i>	Date 12/13/03

Walter C. Flensburg
09/11/2003 09:42 AM

To: amiessi@structint.com
cc:
Subject: Pump Shaft Dimensions Rev. 1

There is a revision to the attached dimensions. The necked down region should be 1.562 **not** 2.562 as shown in the sketch.

Cory Flensburg

----- Forwarded by Walter C. Flensburg/CEI/FirstEnergy on 09/11/2003 09:52 AM -----

Walter C. Flensburg
09/11/2003 09:10 AM

To: amiessi@structint.com
cc:
Subject: Pump Shaft Dimensions

Angah:

Attached are the pump shaft end dimensions. If more dimensions are needed please provide a sketch so that we give you exactly what is needed.

Thanks,

Cory Flensburg 440 280- 7363

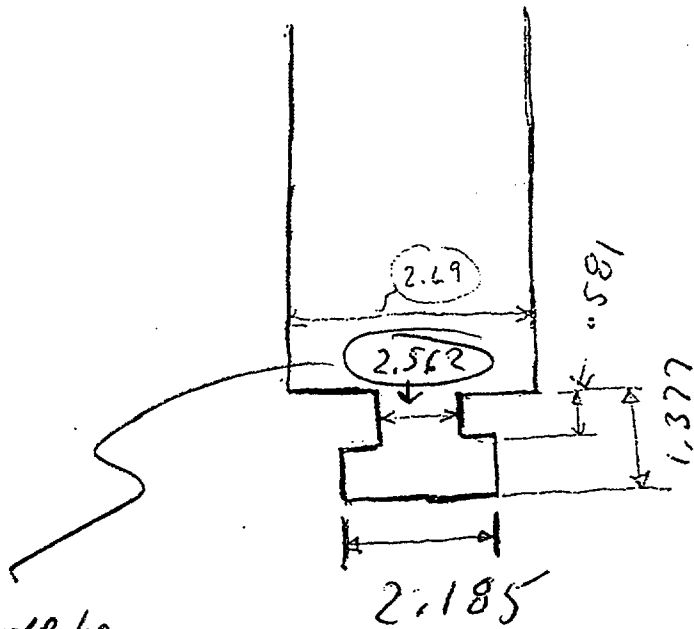


Pump Shaft Dimensions0001

(DIAL CALIPER)

- 0L80E0058F

DUE 9/25/03



Should be
1.562 per
M. BAY

W. L. Slawky 11/1/03

Walter C. Flensburg
09/09/2003 03:19 PM

To: amiessi@structint.com
cc:
Subject: Perry Failed Coupling Design Inputs

Angah:

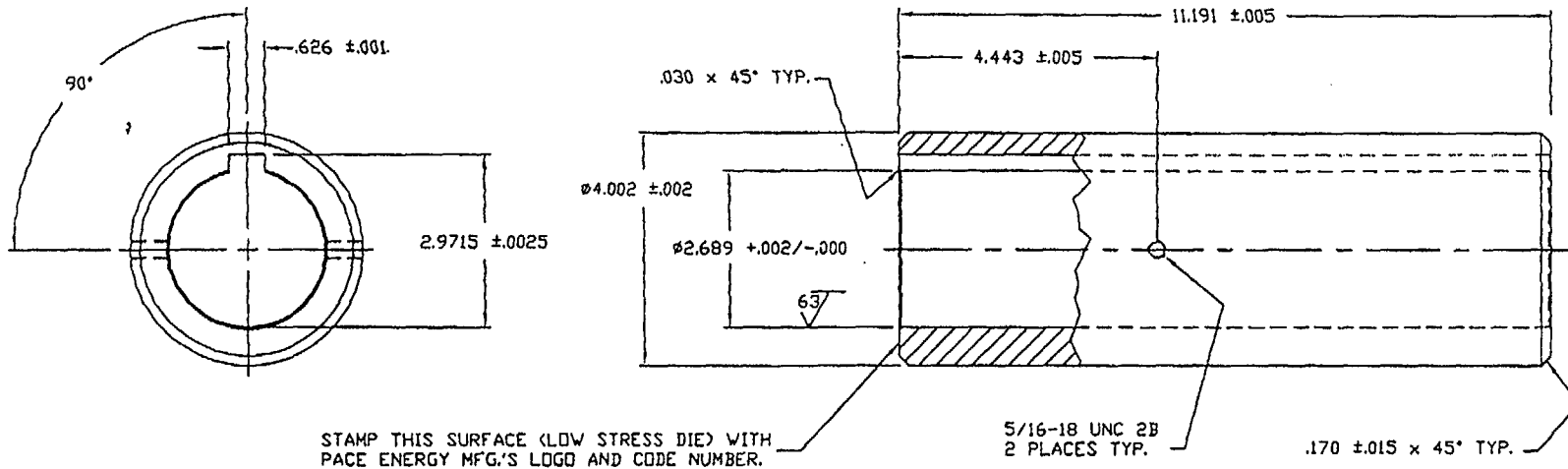
Attached is the Addendum # 1 to the Seismic Report. Portions of the Rev 0 report sent in Acrobat File are superceded by this information.

Cory Flensburg



Addendum 1 Seismic Report000 Addendum 1 Coupling Arrangement000

"REVERSE ENGINEERED" COUPLING DRAWING

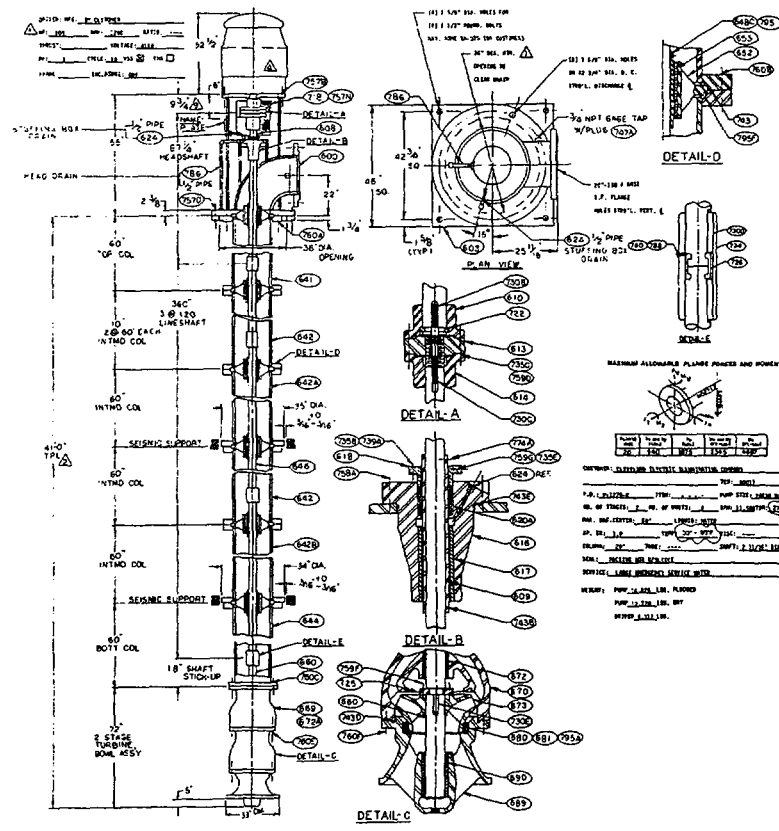


NOTES:

1. MATERIAL TO BE IN ACCORDANCE WITH ASTM A582, TYPE 416 (UNS S41600), CONDITION 'T', (248 TO 302 HARDNESS HB).
2. ALL DIMENSIONS ARE IN INCHES.
3. 125 MICRO ALL OVER UNLESS OTHERWISE INDICATED.
4. BREAK ALL SHARP EDGES.
5. ALL TAPPED HOLES TO BE CLEANED AND FREE FROM BURRS.
6. SPECIFICATIONS: 10CFR21, 10CFR50 APPENDIX 'B', ANSI N45.2, AND NQA-1 APPLY TO THIS ITEM.

TOLERANCES (EXCEPT AS NOTED)		PART NAME		REV'D	MATERIAL
DECIMAL:		PACE ENERGY, INC. 4800 Bullock Rd. • Wauseon, OH 44894			
* NOTED					
FRACTIONAL:		COUPLING			
+ .XXX					
ANGULAR:		DRAWN BY: JD	SCALE: HALF	NATURALS: AS NOTED	DRAWING NO.:
+ 1°		1	9/3/03	DRAWN FROM SKETCHES	DATE: 9/3/03
		No.	DATE	REVISIONS	APPR
					SHAC30393

PRE Attachment 1
 Page 4 of 11



ITEM NO.	DESCRIPTION	MATERIAL
101	SHAFT	SAE 52100
102	KEY	SAE 52100
103	KEYWAY	SAE 52100
104	KEYWAY	SAE 52100
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106	KEYWAY	SAE 52100
107	KEYWAY	SAE 52100
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NOTES

1. ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED ARE IN INCHES.
2. DIMENSIONS IN PARENTHESES ARE FOR INFORMATION ONLY.
3. DIMENSIONS IN SQUARE BRACKETS ARE FOR INFORMATION ONLY.
4. DIMENSIONS IN CIRCLES ARE FOR INFORMATION ONLY.
5. DIMENSIONS IN TRIANGLES ARE FOR INFORMATION ONLY.
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11. DIMENSIONS IN ALL CAPS ARE FOR INFORMATION ONLY.
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13. DIMENSIONS IN MIXED CASE ARE FOR INFORMATION ONLY.
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RECEIVED
MAY 18 1988

PERRY NUCLEAR POWER PLANT
10 CENTER RD, PERRY OHIO 43084

GROUP NUMBER

ENGINEERING SERVICE WATER PUMPS
MODEL 101 2000 B.W. - 3 STAGE

DATE

BY

SCALE

DATE

NO. 22 - 0125-00000 2

DESIGN DRAWING

REV

Comments on Structural Integrity Stress Analysis
File N. PERY-03Q-301

1. Objective

The objective states "stress analysis will be done for the properly centered and off-centered pump shaft coupling assemblies then perform stress analyses to evaluate the impact of the misalignment on the coupling."

a) Comment:

A table is presented for the maximum component stresses in Section 5 but there is only a single table presented in section 5.2 for primary stress comparison. Is this single table the centered or off-centered configuration.

2. Finite Element Model

a) Fig. 9, the stress distribution is noted as "Overall Hoop Stress Distribution". Is there a particular plane through which this hoop stress is taken in the coupling or is it the peaks at any location in the coupling in the hoop direction. It is assumed that the range of stresses (on the right side of Fig 9) are for the coupling not the shaft or key.

b) Fig. 13, provide a general explanation of what this figure is and how it is used.

3. Material properties

a) Is there more explanation needed with regard to tempering of the coupling and effects on properties? As discussed previously, the key may be in either the annealed or temper condition.

4. Analysis

a) Add a note that states how the torque is applied to the shaft and that resulting localized effects in the shaft far enough away (provide basis) from the shaft coupling area of concern so as not to influence results.

5.0 Results and Conclusions

a) Explain why only tensile stresses are shown.

5.2 Primary Stress Comparison to Allowables

a) Change reference 2 to 3

b) The first stress comparison table:

The split ring axial stress is 21,580 psi and includes seismic source addendum 1 to ME 454

Key shear stress is 12491 no seismic source addendum 1 to ME 454

Shaft stress intensity is 21,882 does this include seismic? Note, after further review it has been discovered that the summary sheet in the seismic report sent to you is for a smaller pump. A page by page review of my E-mail has found that the summary is the wrong one and the correct stress can be found on page 21 of the report you have and the value is 29,155 psi.

Do the ANSYS results include the seismic and deadweight contribution? If not, does the comparison have any meaning?

Also which configuration is this, the centered or off-centered? Please supply both configurations.

Can you supply a little more detail as to how the finite element numbers are determined from the output?

Please provide a conclusion with the calculation

General Comments on Preliminary Sleeve Analysis Results:

Peak Stress

This stress will always exist due to the discontinuity at the corner. What is the industry standard for addressing the finite element stresses at this location? Take a linearized stress thru thickness based on bending. Linearize stress through thickness used 30,000 psi in stress.

Is there a strain criteria? NO

Is there a concern with the existing design and operating systems? (Pump B rebuilt in Spring of 2003 and Pump A just rebuilt in Sept. 2003) - Does not feel we have a problem.

Resultant Stress

How will stress results be combined? based on stress in set
PRI

Other

What was the final torque value used in the analysis? would can we gauge the reduction in HP effort
48,000 x 1.1.

What is the orientation of local and global coordinate system in the model? $S_1 - 59,000 + 96,000$
 $S_2 - 63,000 + 33,000$

The key may be in the annealed condition will this impact the analysis?

↳ Look @ worst case

Plots are based on cyl coord. Y is circ. hoop. "S₁"
Z is along axis "S₂" up & down.
X is Radial.

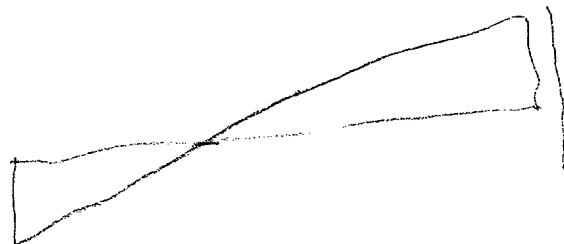
→ From failure report crack is opened by hoop (tangential stress)
→ PRI

4110 volts. Run @ 94 amps

900HP? 102 amp.

pulls 175 HP.

Service factor on motor



Comments on Fracture Analysis of a Normal Coupling

1.0 Objective

1 Why is only the normal configuration discussed?

Linear elastic fracture can factor results.

2.0 Finite Element Analysis

1. At the end of the first paragraph, could we state that the purpose of the second model is to show the relative influence of crack length on the calculated stress intensity and crack depth. As shown in Figure 12 a best fit curve of the calculated K at various crack depths lies in between the assumed crack lengths therefore, the length of the crack is not critical. Therefore, when a crack radial depth is specified in the remainder of this report, the crack length is the full length of the coupling. In your words....

ok.

see Fig. 2 Top dead center.

2. 4th paragraph what is the thickness. You report $t = 0.3451$ We get around $.37 \cdot 4.000 - 2.974 = 1.026$ and $1.026 - .6545 = .3715$ Note that your Table 2 Note 1 has 0.37

CRACK is at groove

3.1 Stress Intensity Factor Determination

1. 1st paragraph.. In the root cause report I added the words below with respect to the set screws. The reason I am bringing it up is that Figure 11 may be impacted so some qualifying words may be in need.

The initial investigation observed that the set screws in the improper configuration could be a significant contributor to the failure of the coupling. It was later determined that the set screws play an insignificant role. The reasoning is as follows. The set screws are required to be snug tight and lock wires are connected between the two set screws to prevent rotation out of the coupling. A snug tight condition is expected to present a small increase in load relative to the applied torque presented from the motor. If the set screws were substantially torqued, the effect on the coupling would be to increase local stresses in the area of the threaded hole in the coupling. This is because the tight fit between shaft and coupling restrict the relative displacement between the two components. Thus the resulting stress from the set screw will remain local to the point of applied load. Additionally, metallurgical testing has confirmed that crack initiation took place at the short end of the coupling away from the set screw hole. Therefore, the set screw is not modeled in the finite element analysis as it will have little effect in end of the coupling where the crack initiated. Stresses at the critical keyway locations will be determined for these two models and used for the fracture mechanics evaluation in Task 2.

This work

3.2 Fracture Toughness

1. First paragraph: The fracture toughness, K_{Ic} , is the critical value of the stress intensity factor K_I at which brittle fracture is predicted to occur. K_{Ic} can be considered a material constant in a given metallurgical condition and under given conditions of temperature and loading rate. Thus K_{Ic} for a given material can be measured in a laboratory. If the calculated stress intensity, K_I , based on the components geometry, stress and crack size exceed the fracture toughness, K_{Ic} , then brittle fracture will occur. Explicit values of Type 416 steel are not available, however, bounding values may be established based on similar materials. Reference 4.....

ok

2 second paragraph could you please submit a copy of the Rolfe and Barsom applicable reference pages. Also I could not get the units to balance in the formula as written.

a version is in section III

3 third paragraph Please submit applicable reference 6 data with final calc.

4. Third paragraph add a summary statement.. Therefore the fracture toughness assumed in this analysis is

3.3.1 Material Test....

1. Second to last paragraph the 10-12 % solution of sodium... Add solution

3.3.2 Stress Corrosion Crack Growth

1. What is a 12 Cr steel? Is this a type 420? Can you add a discussion as to why this is applicable to type 416.
2. Figure 6 do we need to know loading rate, type of stress uniform or residual stress field through which the the figure was developed? Is there a quotable or reference ASTM spec for development of the curve?
3. Add a conclusion to the paragraph. Therefore, the IGSCC crack growth rate is conservative or bounding for our case because....

DAN ReRoute.

Found more curves for higher amplitude. Linear trend should not change the results.

crack increments flow calculates growth

3.3.3 Fatigue Crack Growth

You lost me here and the applicability of this curve, Figure 7. Also the stress intensity range is low. What is meant by the upper bound of the curves? Please add a concluding statement.... Therefore this crack growth rate is applicable to Perry because

4.1 Stress Intensity Factor Results

1. Change Figure 9 to Figure 11 and Figure 10 to 12
2. Second to last sentence ...factors remain the approximately.. remove the
3. Please note the set screw discussion above with respect to ignoring the stress in the coupling

4.2.1 Stress Corrosion Crack Growth Results

1. 1st sentence as shown in Figure 11 should this be figure 6
2. $1000 \times 2.24 \times 10^{-4} \text{ in/hr} = .224 \text{ inches vs } .227$ also 2.047 @ 9140 hours vs 2.077
3. Is the time duration here independent of operating stress or residual stress or will they add to the growth rate?

4.2.2 Fatigue...

1. Could you explain if Figure 7 is used in this section if so how?

we the actual per

CRACK → Residual stress not credited
→ because curve is flat @ 550 psi cause it may be in compression
→ RC CRACK

5.0 Conclusions

1. Third paragraph the 1520 hours will change if you agree to change the thickness to .37 vs .3451
2. Fourth paragraph Add more explanation as to why the fatigue failure is less probable? Is this based solely on the number of starts? - Calculator they did work:
3. Last recommendation Do you have any suggestions or guidance that relates radii to stress intensification that can be added to the report and that I could share with the vendor?

STRAIGHT CHAMFER

Tables #2 Does 1 start = one cycle *yes.*

Figures:

#6 Identify stress field or ASTM spec under which curves are developed

#7 How is this low stress intensity range data applicable to the stress seen during one cycle ?

→ Reviewing

DAN:

- To discuss ~~ing~~ IGSCC initiation.

Telecon

With: Structural Integrity, Dan Delwiche, Angah Miessi

By: C.Flensburg

Subject: Fracture Mechanics Questions
Calculation Pery-03Q-302

Date: Oct. 10, 2003

This teleconference was in response to questions that had resulted from the review of the subject calculation.

1. Why is use of Figure Figure 6 for 12 Cr steel appropriate for type 416 material?

Europeans in the late 60's and 70's developed the curve to be applicable to type 403/410/ and 416 stainless steels that were martensitic. An alloy of 12 Cr and .2 Carbon was identified as fully martensitic and the curve used in figure 6 was developed by Markus Spadel (spelling?) a recognized leader in the field. The curve is considered a dead ringer for 410 SS but also is applicable to 403 and 416 SS. Historically, 410 SS is used in turbines and 416 is used in free machining applications. The high sulfur content in 416 makes the material easier to machine. Therefore, minor differences exist but the martensitic family behaves relatively the same. Martensitic material strength and resistance to corrosion are greatly affected by heat treatment. A heat treatment to 200-300 degrees C (392-572 degrees F) produces high strength but also leaves the material highly susceptible to stress corrosion cracking (SCC). Tempering to 650-750 degrees C (1170-1382 degrees F) leaves the material weaker but more resistive to SCC.

2. There exist three mechanisms limiting the life of the coupling sleeve.

- Fatigue which in our case is small for a small initial defect
- Pitting followed by stress corrosion: The pits allow a site for stress corrosion cracking to initiate. The pit is likely the result of the sodium hypochlorite attack of the susceptible material. How fast the pits form is a function of time and the ability of the crevice to accumulate sufficient free chloride to begin the process.
- Temperature heat treat condition affecting sensitivity of the material

All these conditions impact the life expectancy of the coupling sleeve which in turn affect the use of Figure 6.

3. Recommendation for what is installed

It was explained that B pump had been reworked in April 2003. The recommendation was to obtain the chemistry and heat treatment of what is installed and supply a qualitative argument for what is installed for both both A, B, and C pumps.

4. It was asked if there was any knowledge of ECCS pump coupling (type 410) performance issues.

It was stated that there were no known failure of couplings however an industry search should be made and arguments presented.

5. Failed Coupling

It was explained that our coupling that failed, if tempered at 575 deg. C (1067 deg. F), would be right on the edge of bad things happening. The "bad actors" in order of importance are:

- Carbon Content the higher the carbon the more martensitic the material becomes and the greater the sensitivity to tempering. .15 % Carbon presents a greater risk to SCC.

- Mn (manganese) presents lesser effect than carbon
- Cold Working causing a localized increase in hardness. There is a strong correlation to hardness and SCC
- If hardness is on the order of 30 you are asking for trouble.

6. Calc. Comments on Figure 7

In the review it was noted that the stress intensity range was low for the fatigue curve used in the analysis at the levels of stress intensity that exist. Angah indicated that another curve had been found that is more applicable to our situation. The new curve is less steep therefore the results as reported in Table 2 should increase in cycles for the initial crack. Therefore the results as presented are overly conservative.

All other comments had been verbally responded to in a previous phone call with Angah Miessi.