CALCULATION TITLE PAGE

ICCN NO. / PRELIM. CCN NO.	PAGE ____ OF ____
CCN CONVERSION: CCN NO. CCN-	

Calc. No. M-DSC-250 DCP/MMP/FIDCN/FCN No. & Rev. —

Subject STRESS EVALUATION OF UNIT 3 RCP FLYWHEEL Sheet 1

System Number / Primary Station System Designator 1 SONGS Unit 3 Q-Class II

... Spec. Affecting? ☑ NO ☐ YES, Section No. ________ Equipment Tag No. ________

CONTROLLED COMPUTER PROGRAM / DATABASE	☑ PROGRAM ☐ DATABASE IN ACCORDANCE WITH NES&L 41-5-1	PROGRAM/DATABASE NAME(S) ☐ ALSO LISTED BELOW: PCCRACK	VERSION/RELEASE NO.(S): 2

RECORD OF ISSUES

REV. / DISC.	DESCRIPTION	TOTAL SHTS. / LAST SHT.	PREPARED (Print name/initial)	APPROVED (Signature)	
0	INITIAL ISSUE	42 / 42	ORIG NABIL EL-AKKY/NME D. KAPICH / DK	GS [signature] 11/8/91	Other
			IRE J. Gaw /JG	DM [signature]	DATE 11/8/91
			ORIG	GS	Other
			IRE	DM	DATE
			ORIG	GS	Other
			IRE	DM	DATE
			ORIG	GS	Other
			IRE	DM	DATE

Space for RPE Stamp, identify use of an alternate calc., and notes as applicable.

This calc. was prepared for the identified DCP/MMP. DCP completion and turnover acceptance to be verified by receipt of a memorandum directing DCN Conversion. Upon receipt, this calc. represents the as-built condition. Memo date ________ by ________

SCE 26-121-1 REV. 9/91

CALCULATION CROSS-INDEX

ICCN NO./ PRELIM. CCN NO.	PAGE ___ OF ___
	CCN CONVERSION: CCN NO. CCN--

Calculation No. M-DSC-250 Sheet No. 2

Calc. rev. number and responsible supervisor initials and date	INPUTS These interfacing calculations and /or documents provide input to the subject calculation, and if revised may require revision of the subject calculation.		OUTPUTS Results and conclusions of the subject calculation are used in these interfacing calculations and/or documents.		Does the output interface calc/ document require revision?	Identify output interface calc/document CCN, DCN, TCN/Rev. or FIDCN
	Calc/ Document No.	Rev. No.	Calc/ Document No.	Rev. No.	YES / NO	
0	UPDATED FSAR, UNITS 2&3.		———			
0 pcl 4/8/91	"Flywheel Design Report", Document number AA001-0001.	1				

SCE 26-424 REV. 8/91

Printed on recycled paper

NES&L DEPARTMENT

CALCULATION SHEET

CCN NO./ PRELIM. CCN NO.	PAGE OF
CCN CONVERSION CCN NO. CCN -	

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-230

Subject See Title Sheet Sheet No. 3

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N. M. EL-AKILY	11/07/91	J-G	11/8/91					

TABLE OF CONTENTS

		Sheet Number
	CALCULATION TITLE SHEET	1
	CALCULATION CROSS INDEX	2
	TABLE OF CONTENTS	3
1	PURPOSE	4
2	RESULTS/CONCLUSIONS	5
3	ASSUMPTIONS	6
4	METHODOLOGY	7
5	DESIGN INPUT	14
6	REFERENCES	16
7	NOMENCLATURE	17
8	CALCULATIONS	19

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N. M. EL-AKILY	11/07/91	S.G.	11/8/91					

1 PURPOSE

The purpose of this calculation is to perform a stress evaluation of the Reactor Coolant Pump (RCP) flywheel, Unit 3, for brittle fracture. The results of the analysis will be used to provide technical basis for a waiver of compliance from the requirements of Technical Specification (TS) Limiting Condition for Operation (LCO) 3.0.3 and 3.4.1.1 until February, 1992. These LCO's relate to the inspection schedule associated with the RCP motor flywheels per TS 4.4.9.

NES&L DEPARTMENT
CALCULATiON SHEET

ICCN NO./ PRELIM. CCN NO. | PAGE OF

CCN CONVERSION CCN NO. CCN -

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-250

Subject See Title Sheet Sheet No. 5

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N. M. EL-AKILY	11/07/91	J Gour	11/8/91					

2 RESULTS/CONCLUSIONS

The stress intensity factor, K_I, was calculated for a crack depth of 0.6" representing the depth of the keyway plus twice the depth of the largest nondetectable crack. The flywheel loading combinations, included rotating disk stress, interference fit stress, key loading due to pump coast down deceleration, seismic loading and vibratory motion. All loads were calculated assuming overspeed condition; thus representing the most severe conditions. A safety factor (SF) was then calculated as follows:

$$SF = \frac{K_{IC}}{K_I} = 4.7 \quad \text{(See Section 8)}$$

Where K_{IC} is the critical stress intensity for the flywheel material at the operating temperature (=220 ksi$\sqrt{\text{in}}$, Reference 1). It was concluded that the case of pump rotor seizure and motor acceleration are enveloped by the pump overspeed conditions. It was also concluded that start-up stresses are enveloped by the pump overspeed conditions.

Total crack growth of 0.005" was calculated based on 100 pump stop and start cycles (the projected total number of cycles for the duration between 2/1/87 and 2/29/92 is less than 50).

Based on the above results, it was concluded that continued operation until 2/29/1992 will not result in crack propagation resulting in loss of flywheel structural integrity.

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
2	N. M. EL-AKILY	11/07/91	J.G.	11/8/91					

3 ASSUMPTIONS

3.1 The dominant stress components in the flywheel are the tangential stress (σ_t) and the radial stress (σ_r). The axial stress component (σ_z) is small since the loads acting on the flywheel in the axial direction are significantly less than the loads in the plane of the flywheel. Specifically, the tangential stress due to vertical seismic acceleration (z-direction) is only 2.5% of the total tangential stress.

3.2 The flywheel is keyed to the eight spider arms by two axial keys. However, it was conservatively assumed that the deceleration load due to coast down is supported by one key only.

3.3 The speed of pump is proportional to the rate of flow in the reactor coolant loop.

3.4 The tangential stress is of primary concern in the fracture mechanics calculations since this stress component acts perpendicularly to the crack. Although shear stress (radial stress) which acts parallel to the crack represents a Mode II crack opening, this mechanism of failure rarely occurs and will not be considered since the radial stress is smaller than the tangengial stress.

4 METHODOLOGY

4.1 Stress Evaluation

The fracture mechanics evaluation of the flywheels at Units 2 & 3 is based on the methodology of the vendor's design report (Reference 1). Only Mode I edge cracks at the bore were considered, as explained in Section 3, since the maximum stress component is in the tangential direction (σ_t). Conservatively, the depth of the keyway was added to the crack depth.

A combination of static and dynamic loads act on the flywheel simultaneously during operation. The total stress, therefore, is equal to the sum of the individual components due to each type of loading. Specifically, the total load (or stress) is the sum of the following:

(a) Rotating Disk Stresses

The tangential stress, as a function of the radius (r), and the angular velocity (w), due to rotation is given by the following expression (Reference 1):

$$\sigma_t = \rho \omega^2 \left(\frac{3+\nu}{8}\right)\left[a^2 + b^2 + \left(\frac{ab}{r}\right)^2 - \left(\frac{1+3\nu}{3+\nu}\right) r^2\right] \quad (1)$$

where

$15.5'' \leq r \leq 41''$ (Reference 1)

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N. M. EL-AKILY	11/07/91	J-C.	11/8/91					

(b) Interference Fit Stresses (ΔR)

The stress in the flywheel is due to the interference fit between the flywheel and the spider arms. The stress is a function of the interface pressure P_s, which is a function of W and the initial interference ΔR.

It was calculated in Reference 1 that

$$\sigma_t = \begin{cases} 1.334 P_s & (\text{at } 1180 \text{ rpm}) \\ 0.334 P_s & (\text{at } 1500 \text{ rpm}) \end{cases}$$

where (Reference 1),

$$P_s(max) = \begin{cases} 2920 \text{ psi} & (\text{at } 1180 \text{ rpm}) \\ 850 \text{ psi} & (\text{at } 1500 \text{ rpm}) \end{cases}$$

(c) Key Loading

The torque (T_Q) due to the deceleration of the RCL pump is calculated as follows:

$$T_Q = \left(\frac{d\omega}{dt}\right) I_p$$

This torque is transmitted to the flywheel through the axial keys, which results in a tangential load acting on the flywheel at the axial key. This load (F_{KEY}) is calculated as follows:

$$F_{KEY} = \frac{T_Q}{a} \qquad (3)$$

where is assumed that one key is only transmitting the coast down deceleration torque to the flywheel. (See Section 3).

NES&L DEPARTMENT

CALCULATION SHEET

ICCN NO./ PRELIM. CCN NO.	PAGE OF

CCN CONVERSION
CCN NO. CCN -

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-250

Subject See Title Sheet Sheet No. 9

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N. M. EL-AKILY	11/07/91	J-Go	11/8/91					

(d) Seismic Loading

Seismic loads were calculated based on the following acceleration components: (See Section 5)

$$A_H = 2.5g$$

$$A_V = 3.5g$$

Tangential stress due to horizontal acceleration is given by: (Reference 1)

$$\sigma = \frac{F}{A}$$

$$F = \frac{1}{2} m A_H$$

where A = T (a-b).

Bending stress due to vertical acceleration is calculated as follows:

total distributed load (w) $= \frac{m}{\pi(b^2-a^2)}(A_v+g)$

$$= \frac{m}{\pi(b^2-a^2)}(3.5+1)$$

maximum tangential stress occurs at the inner diameter; and it is given by: (Reference 2)

$$\sigma_t(max) = \frac{3w}{4\nu' t^2(b^2-a^2)}\left[4b^4(\nu'+1)\log\left(\frac{b}{a}\right) + 4a^2b^2 + a^4(\nu'-1) - b^4(\nu'+3)\right] \quad (4)$$

where $\nu' = \frac{1}{\nu} = \frac{1}{0.3} = 3.33$

Shear stress is negligible (it was calculated at 106 psi in Reference 1).

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N. M. EL-AKILY	11/07/91	J.G.	11/8/91					

(e) Stresses due to Vibratory Motion

This analysis is based on the maximum allowed eccentricity in the orbit of the flywheel (Reference 5). The radial force, F_r, is given by:

$$F_r = \omega^2 r_c m$$

This radial force results in tangential stress of:

$$\sigma_t = \frac{F_r}{2(b-a)t} \qquad (5)$$

as explained in Figure 4.1 below

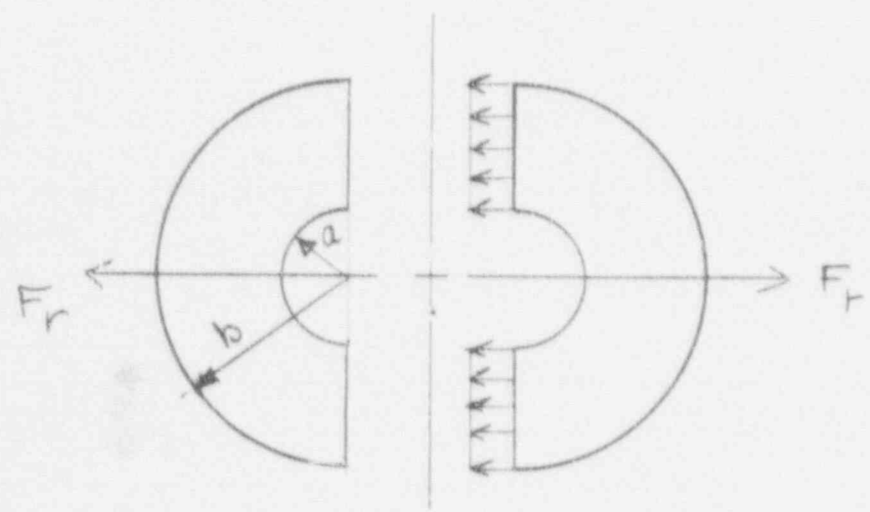


Figure 4.1 Stress due to Vibratory Motion

NES&L DEPARTMENT

CALCULATION SHEET

ICCN NO./ PRELIM. CCN NO.	PAGE OF

CCN CONVERSION CCN NO. CCN -

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-250

Subject See Title Sheet Sheet No. 11

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	W. M. EL-AKILY	11/07/91	J. G.	11/8/91					

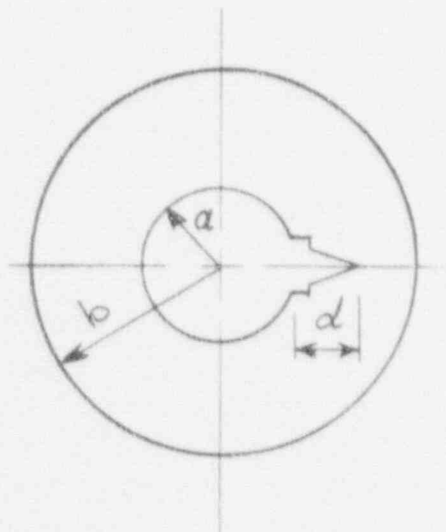
The total tangential stress, σ_t, is given by the sum of the components calculated in this Subsection, i.e.,

$$
\begin{aligned}
\sigma\ (\text{total}) = {} & \sigma\ (\text{rotating disk stress}) + \\
& \sigma\ (\text{interference fit stress}) + \\
& \sigma\ (\text{key loading stress}) + \\
& \sigma\ (\text{seismic}) + \\
& \sigma\ (\text{vibratory motion}) \qquad (6)
\end{aligned}
$$

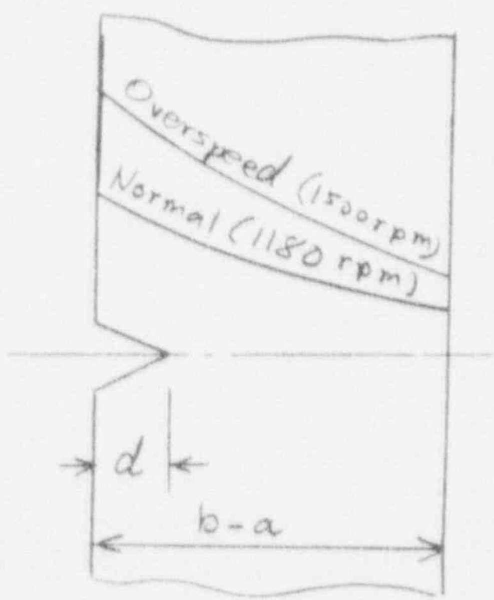
An additional evaluation was made assuming pump rotor seizure. An upper bound key loading, corresponding to failure in the curvic coupling, was calculated and the total stress in this case was based on the normal speed condition. Details of this analysis can be found in Section 8 of this calculation

4.1 Crack Growth Evaluation

A radial crack, of depth d, was postulated, and the model shown in Figure 4.2 was used to calculate the stress intensity factor versus crack depth.



A. Postulated Crack



B. Analysis Model

Figure 4.2 Model for Brittle Fracture

NES&L DEPARTMENT
CALCULATION SHEET

ICCN NO./ PRELIM. CCN NO.	PAGE OF
CCN CONVERSION CCN NO. CCN -	

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-250

Subject See Title Sheet Sheet No. 13

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N. M. EL-AKILY	11/07/91	J-G	11/8/91					

The computer program PCCRACK was used to perform the analysis, and calculate the stress intensity factor (K_I). Based on the calculated K_I, a comparison was made with the critical stress intensity factor of the flywheel material (K_{IC}) to calculate the safety factor.

A crack growth evaluation is made based on $\Delta K = K_I$ for one cycles.

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N. M. EL-AKILY	11/07/91	J.C.	11/8/91					

5 DESIGN INPUT

- Flywheel Description: (Reference 1)

Figure 5.1 shows the assembly of the flywheel, the shaft and the eight spider arms. The flywheel has the form of a disk with outside diameter of 82", inside diameter of 31" and thickness of 7.9". The flywheel is attached to the eight rotor shaft spider arms by a heavy interference fit, and keyed by two axial keys and six circumferential keys.

- Material Properties: (Reference 1)

Material - ASTM A-543-72 GrB, Class I

Young's Modulus (E) - $30X10^6$ psi

Poisson's Ratio (μ) - 0.3

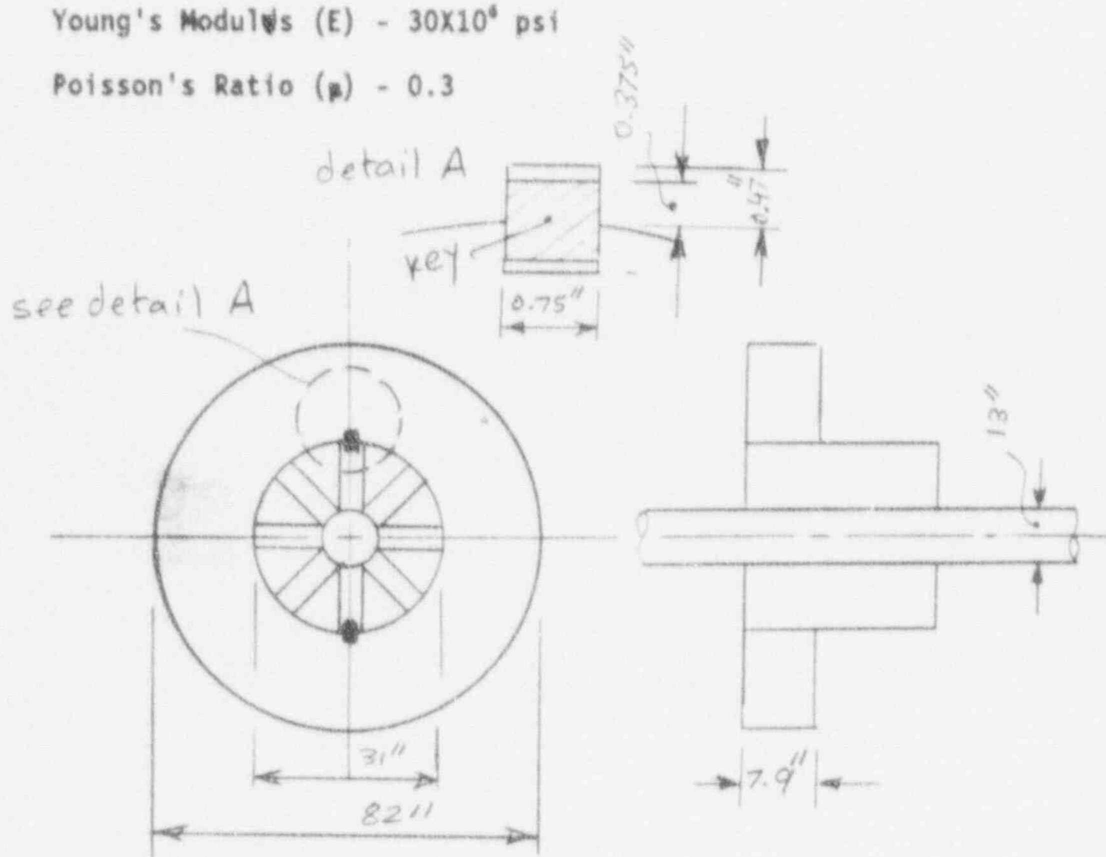


Figure 5.1 Flywheel, Spider Arms and Shaft Assembly

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N. M. EL-AKILY	11/07/91	J.G.	11/8/91					

Mass density (p) - 0.000735 $lb_f\ sec^2/in^4$

($490.8\ lb_m/ft^3$)

Yield Strength - 85 ksi

Ultimate Strength - 105 ksi

Critical Stress intensity factor (K_{IC}) - 220 ksi$\sqrt{in}$

- <u>Rotational Speed</u> (Reference 1)

Design Overspeed - 1500 rpm

(w = 157.1 rad/sec.)

Normal Speed - 1180 rpm (1200 rpm used conservatively)

(w = 123.6 rad/sec.)

- <u>Weight</u> (Reference 1)

Weight - 10,115 lb

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N. M. EL-AKILY	11/07/91	J-G	11/8/91					

6 REFERENCES

1. "Flywheel Design Report, Flywheels for Reactor Coolant Pump Motors for: Southern California Edison Company, San Onofre Nuclear Generating Station, Units 2, and 3", Report No. 0501-4827, Revision 1, Allis-Chalmers Corporation, October 4, 1978. SCE number AA001-0001.

2. "Formulas for Stress and Strain", R.J. Roark, McGraw-Hill book Company, 4th Edition, 1965.

3. Letter from M. Stickel, Westinghouse Site Services Manager to S. Gosselin, SCE dated October 26, 1991. Subject: SONGS Unit 1 Flywheel Specifications.

4. Final Safety Analysis Report (FSAR), Units 2 & 3.

5. Document: SO 23-3-1.7, "Reactor Cooling Pump Operating Procedure, Unit 3."

6. ASME Boiler and Pressure Vessel Code, Division 1, Section XI, 1977.

7. Document: SO 23-ISI-018, Revision 1, "CE, Ultrasonic Examination Procedure for Reactor Coolant Pumps, Flywheels and Balancing Devices."

8. Document: SO 23-922-35-2, Induction Motor Speed vs. Torque & current curve.

9. Document: SO 23-922-36-4, Induction Motor Calculated Time vs. current curve.

NES&L DEPARTMENT

CALCULATION SHEET

ICCN NO./ PRELIM. CCN NO.	PAGE OF
CCN CONVERSION CCN NO. CCN -	

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-250

Subject See Title Sheet Sheet No. 17

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N. M. EL-AKILY	11/07/91	J.G.	11/8/91					

7 **NOMENCLATURE**

a = Inside radius, in

A = Area, in^2

A_H = Horizontal acceleration, g.

A_V = Vertical acceleration, g.

b = Outside radius, in.

d = Crack depth, in.

E = Young's modulus, psi

F = Force, lb.

K_I = Stress intensity factor for Mode I cracks, ksi$\sqrt{in}$.

K_{IC} = Critical Stress intensity factor for Mode I cracks, ksi$\sqrt{in}$.

I_p = Polar moment of inertia, $lb_m\ in^4$.

m = Mass, lb_m.

N = Number of cycles

v = Poisson's ratio

ω = Angular velocity, rad/sec.

P_s = Interference fit interface pressure, psi

r = Radius, in.

ρ = density, lb/in^3

ΔR = Interference fit interference, in.

σ_r = Radial Stress, ksi.

σ_t = Tangential Stress, ksi.

NES&L DEPARTMENT
CALCULATION SHEET

ICCN NO./ PRELIM. CCN NO. | PAGE OF

CCN CONVERSION CCN NO. CCN -

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-250

Subject See Title Sheet Sheet No. 18

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N. M. EL-AKILY	11/07/91	J. G	11/8/91					

σ_z = Axial Stress, ksi.

T = Time, sec.

t = Thickness, in.

8 CALCULATIONS

8.1 Stress Evaluation

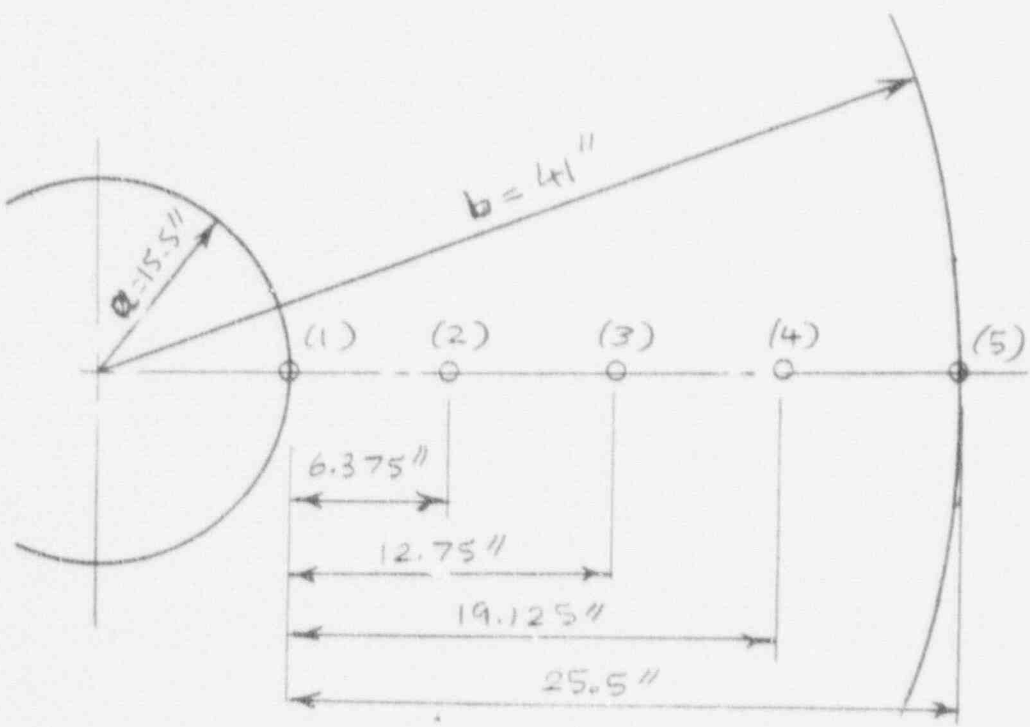


Figure 8.1 Locations at which σ_t was evaluated

NES&L DEPARTMENT
CALCULATION SHEET

ICCN NO./ PRELIM. CCN NO.	PAGE OF

CCN CONVERSION
CCN NO. CCN -

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-250

Subject See Title Sheet Sheet No. 20

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	M. M. EL-AKILY	11/07/91	J.G.	11/8/91					

Tangential stress σ_t was evaluated at equal intervals between r=a and r=b, as shown in Figure 8.1, using equations 1 through 4, Section 4. These stress components were calculated for normal speed (1200 rpm) and design overspeed (1500 rpm), as explained below.

(a) Rotating Disk Stresses

Equation (1), Section 4, was used to calculate the tangential stress due to disk rotation at normal speed (N=1200 rpm), and design overspeed (N=1500 rpm). Results can be summarized as follows:

Location (Fig. 8.1)	σ_t-norm (ksi)	σ_t-overspeed (ksi)
(1)	16.0	25.9
(2)	11.5	18.6
(3)	9.1	14.7
(4)	7.3	11.7
(5)	5.5	8.9

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N. M. EL-AKILY	11/07/91	J. G	11/8/91					

(b) Interference Fit Stresses

Equation (2), Section 4, was used to calculate the tangential stress due to the interference fit at the bore of the flywheel. This stress component is evaluated at normal speed (N=1200 rpm) and overspeed (N=1500 rpm). Results can be summarized as follows:

Location (Fig. 8.1)	σ_t - norm (ksi)	σ_t - overspeed (ksi)
(1)	3.9	1.1
(2)	2.2	0.6
(3)	1.5	0.4
(4)	1.2	0.3
(5)	1.0	0.3

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N. ? L-AKILY	11/07/91	J.G	11/8/91					

(c) Keyway Loading

Per Reference 1, the keyway dimensions are:

Keyway Width = 0.750 in.
Keyway Depth = 0.470 in.
There are two keys 0.75"X0.75" 180° spaced.

In this subsection, the key loading due to flywheel inertia at the time of RCP trip from normal operating condition will be determined. This condition results in maximum rate of change in the pump speed vs. time.

Polar inertia moment of the flywheel, per Reference 2, Page 174, the sectional polar moment of inertia is:

$$I_p = \frac{1}{2}\pi b^4$$

for a circular plate with radius b

Multiplying by the mass density $\frac{\rho}{g}$ and flywheel thickness t,

$$I_{p_{mass}} = I_p \cdot \frac{\rho}{g} \cdot t \ , \ g = 386 \text{ in/sec}^2$$

g is the gravity acceleration.

For wheel with a hole in the center, subtract inertia moment for the missing mass and using steel density ρ = 0.283 $^{lb}/in^3$,

$$I_{P_{mass}} = \frac{\pi(b^4 - a^4)}{2} \cdot \frac{0.283}{386} \cdot 7.9$$

$$b = 41'', \quad a = 15.5''$$

$$I_{P_{mass}} = 25113.5 \quad lb\ in\ sec^2$$

Torque Due to Deceleration

Using a generally known formula,

$$T_Q = I_P \left(\frac{d\omega}{dt}\right)$$

where,

$\frac{d\omega}{dt}$ is the angular acceleration

NES&L DEPARTMENT
CALCULATION SHEET

ICCN NO./ PRELIM. CCN NO.	PAGE OF
CCN CONVERSION CCN NO. CCN -	

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-250

Subject See Title Sheet Sheet No. 24

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	D. KAPICH	11/07/91	J. G	11/8/91					

To calculate $\frac{d\omega}{dt}$, used is F re 3.1.2.1 from the updated FSAR, Reference 4. It is ..sumed that the core flow is closely proportional to the pump speed and therefore could be used to calculate $\frac{d\omega}{dt}$ with sufficient accuracy.

$$\text{initial } \frac{d\omega}{dt} = \frac{7\% \text{ Flow decrease}}{1 \text{ sec.}} = 0.07 \times 1200$$

$$\frac{d\omega}{dt} = 84\left(\frac{2\pi}{60}\right) = 8.796 \text{ rad/sec}^2$$

It follows that,

$$T_Q = 8.796 \times 25113.5 = 220\,890 \text{ in lb}$$

Since at full pump speed the shrink pressure at the flywheel bore is very minimal, it is assumed that the entire inertia torque (T_q) is being transmitted to the shaft via shaft key. One key is conservatively assumed to support the entire torque load, as shown in Figure 8.2.

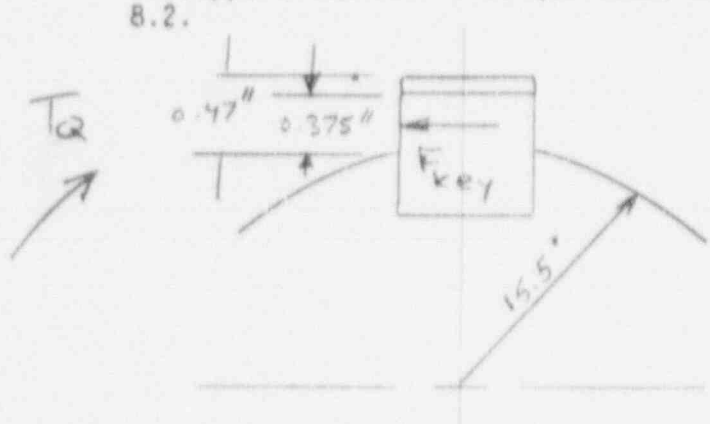


Figure 8.2 Key loading for one key

NES&L DEPARTMENT

CALCULATION SHEET

ICCN NO./ PRELIM. CCN NO.	PAGE ___ OF ___
	CCN CONVERSION: CCN NO. CCN--

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-250

Subject SEE TITLE SHEET Sheet No. 25

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N. EL-AKILY	11/7/91	JC	11/8/91					

REV. INDICATOR

$$T_Q = F_{key} \times R_F$$

$$R_F = \frac{31}{2} + \frac{0.375}{2} = 15.69 \text{ in}$$

$$F_{key} = \frac{T_Q}{R_F} = 14081 \text{ lb}$$

keyway surface load for one key,

$$\sigma = \frac{F_k}{A_{ke}} = \frac{14081}{0.375 \times 7.9} = 4753 \text{ psi}$$

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N. M. EL-AKILY	11/07/91	J.C.	11/8/91					

(d) Seismic Loading

Tangential stress due to DBE load was calculated using equation (4) which gives the maximum value at the bore due to vertical acceleration A_V. This maximum value was conservatively used at each of the five locations defined in Figure 8.1. The DBE stress, which was used in combination with other stress components under normal conditions, was assumed to be equal to one half of the DBE load. The full DBE load was used in the overspeed case.

Results can be summarized as follows:

- Normal conditions (N=1200 rpm),

$$\sigma_t = 0.4 \text{ ksi}$$

- Overspeed conditions (N=1500 rpm),

$$\sigma_t = 0.8 \text{ ksi}$$

The tangential stress due to the horizontal component of acceleration (A_H) was calculated in Reference 1 at 0.03 ksi; it was ignored in this analysis since it is very small compared with the other stress components calculated in this section.

NES&L DEPARTMENT

CALCULATION SHEET

ICCN NO./ PRELIM. CCN NO.	PAGE OF

CCN CONVERSION CCN NO. CCN -

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-250

Subject See Title Sheet Sheet No. 27

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	D. KAPICH	11/07/91	J.G.	11/8/91					

(e) Vibratory Stress due to Synchronous Orbit

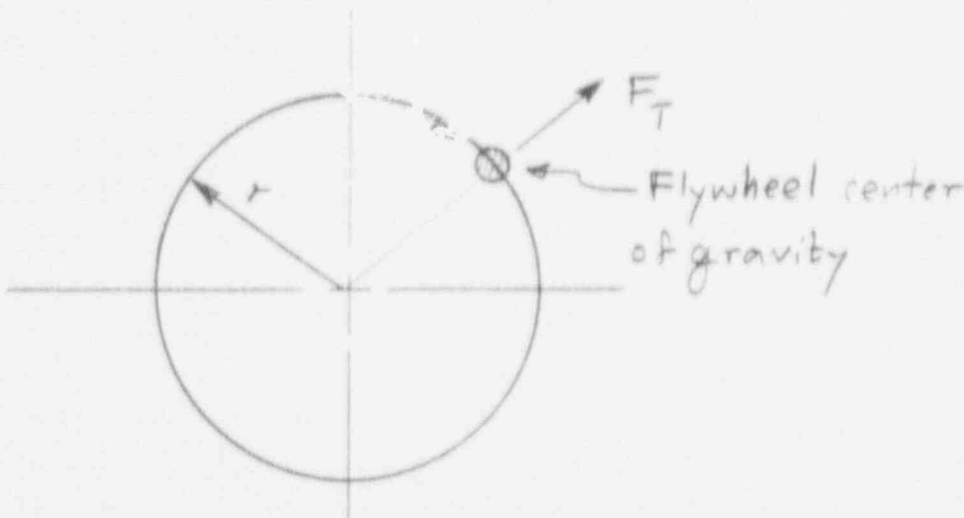


Figure 8.3

Unit 3 RCP's, maximum allowed vibration "Peak to Peak" is
20 mils. (Reference 5)

i.e. r = 0.010 in.

Flywheel mass,

$$W = 10115 \text{ lb} \quad (\text{Section } 5)$$

$$m = \frac{W}{g} = \frac{10115}{386} = 26.2 \text{ lb sec}^2/\text{in}$$

NES&L DEPARTMENT

CALCULATION SHEET

ICCN NO./ PRELIM. CCN NO.	PAGE OF

CCN CONVERSION
CCN NO. CCN -

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-250

Subject See Title Sheet Sheet No. 28

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	D. KAPICH	11/07/91	J. G.	11/8/91					

Flywheel radial force,

Assume design speed = 1500 rpm

$$\omega = \frac{2\pi \times 1500}{60} = 157.1 \text{ rad/sec}$$

$$F_R = m r \omega^2 = 6467 \text{ lb}$$

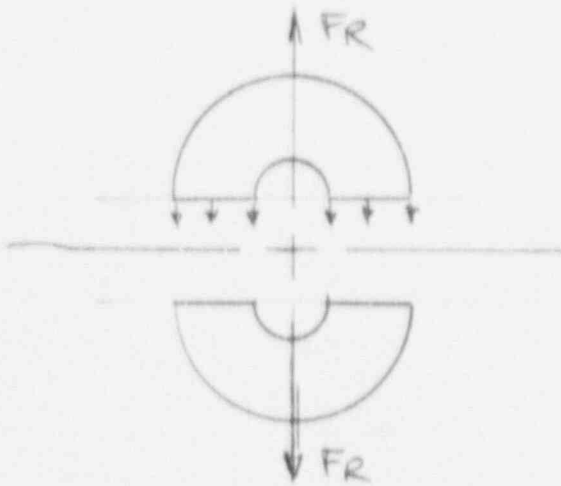


Figure 8.4

NES&L DEPARTMENT

CALCULATION SHEET

CCN NO./ PRELIM. CCN NO.	PAGE OF
CCN CONVERSION CCN NO. CCN -	

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-250

Subject See Title Sheet Sheet No. 29

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	D. KAPICH	11/07/91	J G.	11/8/91					

Assume inner half is supported by the shaft, while outer half tends to fly outward (Figure 8.4)

Stress due to synchronous orbit,

$$\sigma = \frac{F_R}{A} = \frac{6467}{25.5 \times 7.9 \times 2} = 16 \text{ psi}$$

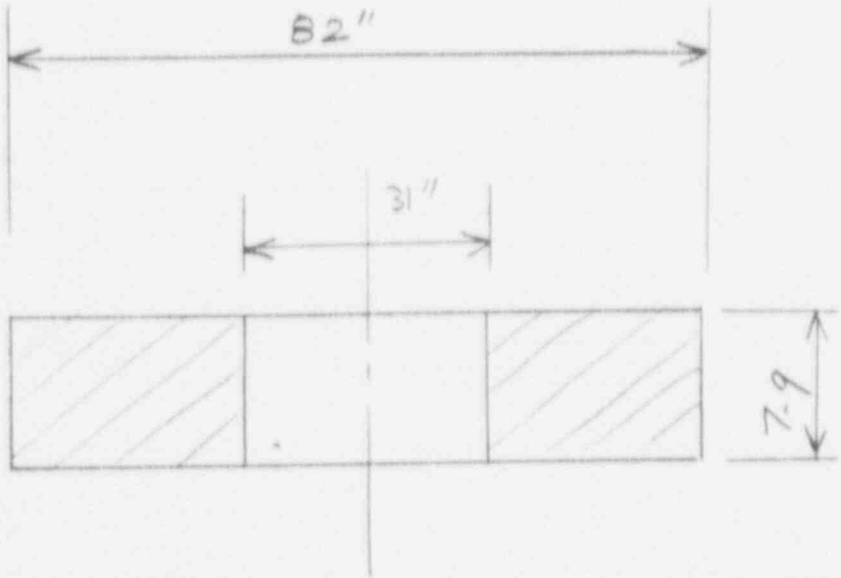


Figure 8.5

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N. M. EL-AKILY	11/07/91	J G	11/8/91					

The total tangential stress is given by equation 6.

It is summarized in Table 8.1 below:

Table 8.1

Total Tangential Stress Distribution

Location (see Figure 8.1)	Total Tangential Stress, σ_t (ksi)	
	Normal Condition (N=120 rpm)	Overspeed Condition (N=1500 rpm)
(1)	25.2	32.7
(2)	14.1	20.1
(3)	11.0	16.0
(4)	8.8	12.9
(5)	6.9	10.0

8.2 Crack Growth Evaluation

The computer program PC CRACK was used to perform linear elastic fracture mechanics (LEFM) analysis on the single edge crack plate shown in Figure 8.6.

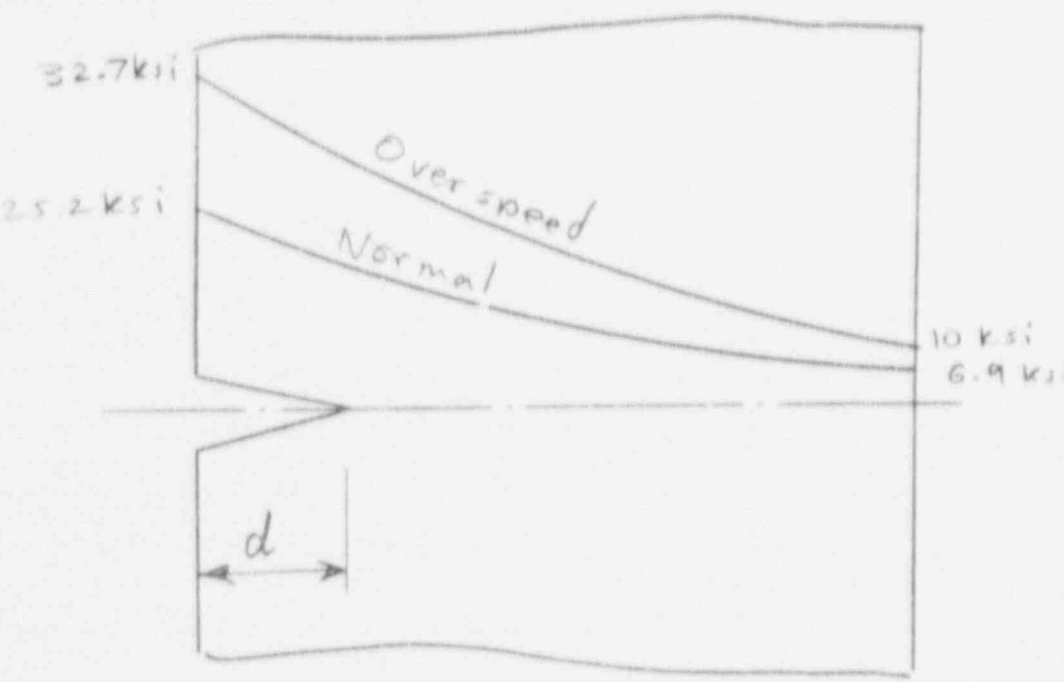


Figure 8.6 LEFM Single Edge Crack Plate

The figure shows the normal and overspeed stress distributions based on Table 8.1.

Analysis was performed for crack depth (d) up to 3". Results of the analysis, in the form of stress intensity factor (K_I) versus crack depth (d), are plotted in Figure 8.7. These results are also listed in Table 8.2

NES&L DEPARTMENT

CALCULATION SHEET

ICCN NO./ PRELIM. CCN NO.	PAGE OF
CCN CONVERSION CCN NO. CCN -	

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-250

Subject See Title Sheet Sheet No. 32

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	W. M. EL-AKILY	11/07/91	J.G.	11/8/91					

8.3 **Numerical Results**

Stress intensity factors are given for different crack depths, $0<d\leq3"$, in Table 8.2. Safety factors can be calculated based on the values of K_I (from Table 8.2) and the critical stress intensity factor K_{IC}, as follows:

$$SF = \frac{K_{IC}}{K_I}$$

where

$$K_{IC} = 220 \text{ ksi}\sqrt{in} \qquad \text{(Reference 1)}$$

Safety factors were calculated for 3 representative cases based on design overspeed condition:

(a) **¼" Crack**

This is larger than the smallest detectable crack (¼ of the keyway depth)

$$SF = \frac{220}{21.4} = 10.3$$

(b) **Keyway depth + 1/8" crack**

In this case, d = 0.47 + 0.125 = 0.595"

$$S.F = \frac{220}{46.5} = 4.74$$

(c) Crack depth equals twice the keyway depth

In this case, d = 0.94"

$$SF = \frac{220}{58.2} = 3.78$$

The crack growth rate is estimated using Reference 6. Maximum crack growth rate (for crack depth of 0.595") is $50X10^{-6}$ in/Cycle.

Conservatively, 100 cycles are assumed

total crack growth = $100x50x10^{-6}$

= 0.005"

NES&L DEPARTMENT

CALCULATION SHEET

ICCN NO./	PAGE ___ OF ___
PRELIM. CCN NO.	
CCN CONVERSION	
CCN NO. CCN--	

Project or DCP/MMP SONGS-3 Calc No. M-DSC-250

Subject SEE TITLE SHEET Sheet No. 34

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE	REV. INDICATOR
0	N.M.EL-AKILY	11/5/91	J.G.	11/8/91						

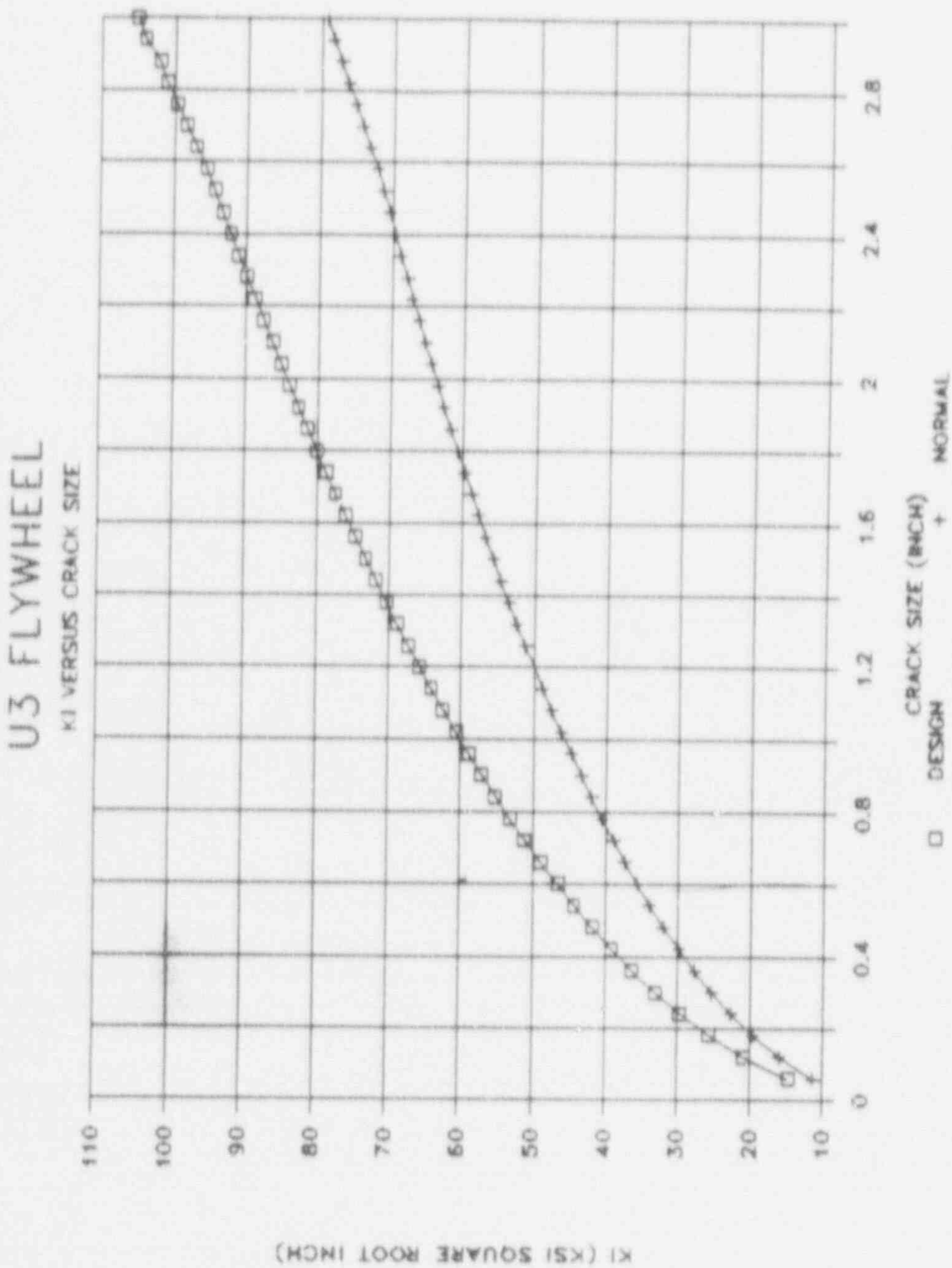


Figure 8.7 Stress Intensity Factor vs Crack Depth

NES&L DEPARTMENT

CALCULATION SHEET

ICCN NO./ PRELIM. CCN NO.	PAGE ____ OF ____
CCN CONVERSION: CCN NO. CCN--	

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-250

Subject SEE TITLE SHEET Sheet No. 35

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	N-M. EL-AKILY	11/8/91	J.C.	11/8/91					

REV. INDICATOR

pc-CRACK tm
(C) COPYRIGHT 1984, 1988
STRUCTURAL INTEGRITY ASSOCIATES, INC.
SAN JOSE, CA (408)978-8200
VERSION 2.0

Date: 27-Oct-1991
Time: 9:55:57.64

LINEAR ELASTIC FRACTURE MECHANICS EVALUATION

NORMAL

crack model:SINGLE EDGE CRACKED PLATE

PLATE WIDTH(b)= 25.5000

STRESS COEFFICIENTS

CASE ID	C0	C1	C2	C3
DESIGN	31.7330	-1.7403	0.0360	0.0000
NORMAL	24.2822	-1.5096	0.0335	0.0000

CRACK ----------------STRESS INTENSITY FACTOR----------------

CRACK SIZE	CASE(1) DESIGN	CASE (2) NORMAL	CRACK SIZE	CASE (1) DESIGN	CASE (2) NORMAL
0.0600	14.805	11.325	1.5600	74.708	56.761
0.1200	20.928	16.006	1.6200	76.098	57.801
0.1800	25.621	19.589	1.6800	77.462	58.821
0.2400	29.573	22.605	1.7400	78.799	59.820
0.3000	33.050	25.255	1.8000	80.112	60.800
0.3600	36.190	27.647	1.8600	81.402	61.762
0.4200	39.073	29.842	1.9200	82.669	62.706
0.4800	41.754	31.880	1.9800	83.914	63.633
0.5400	44.268	33.791	2.0400	85.160	64.545
0.6000	46.644	35.594	2.1000	86.346	65.441
0.6600	48.900	37.306	2.1600	87.533	66.322
0.7200	51.053	38.938	2.2200	88.702	67.190
0.7800	53.116	40.500	2.2800	89.854	68.044
0.8400	55.098	42.000	2.3400	90.989	68.884
0.9000	57.008	43.444	2.4000	92.108	69.713
0.96[illegible]0	58.853	44.838	2.4600	93.212	70.529
1.0200	60.639	46.186	2.5200	94.301	71.333
1.0800	62.371	47.492	2.5800	95.531	72.244
1.1400	64.053	48.759	2.6400	96.905	73.265
1.2000	65.689	49.991	2.7000	98.273	74.281
1.2600	67.283	51.190	2.7600	99.635	75.292
1.3200	68.838	52.358	2.8200	100.990	76.297
1.3800	70.355	53.498	2.8800	102.339	77.297
1.4400	71.838	54.610	2.9400	103.683	78.293
1.5000	73.288	55.697	3.0000	105.020	79.283

(1) Overspeed (N=1500 rpm)

(2) Normal (N=1200 rpm)

Table 8-2

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	D. KAPICH	11/07/91	J.G.	11/8/91					

8.4 Postulated Pump Seizure

It is assumed that the pump impeller, or the 24" main pump bearing, seizes, resulting in almost instant angular deceleration of the pump shaft.

As shown on Figure 8.8, the pump shaft is coupled to the motor shaft via coupling spacer, which is coupled to the pump shaft via curvic coupling.

Torsional Loads

Compared is torsional load into the curvic coupling, with the torsional load into the flywheel keys.

The load into the curvic coupling due to pump seizure consists of:

(a) Electric motor rotor inertia load,

Plus,

(b) Flywheel inertia load

The load into the flywheel keys consist of:

(b) Flywheel inertia only

Therefore, a conservative assumption would be to ignore the electric motor rotor inertia, thus assuming equal torque for both, curvic and the flywheel attachments.

Task

Calculate torque required to fail the curvic teeth and then calculate the stress level in flywheel keys at that point.

NES&L DEPARTMENT

CALCULATION SHEET

ICCN NO / PRELIM CCN NO	PAGE ___ OF ___
CCN CONVERSION	CCN NO CCN-

Project or DCP/MMP SONGS 2&3 Calc No M-DSC-250

Subject SEE TITLE SHEET Sheet No. 37

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	D. KARCH	11/7/91	JG	11/8/91					

REV. INDICATOR

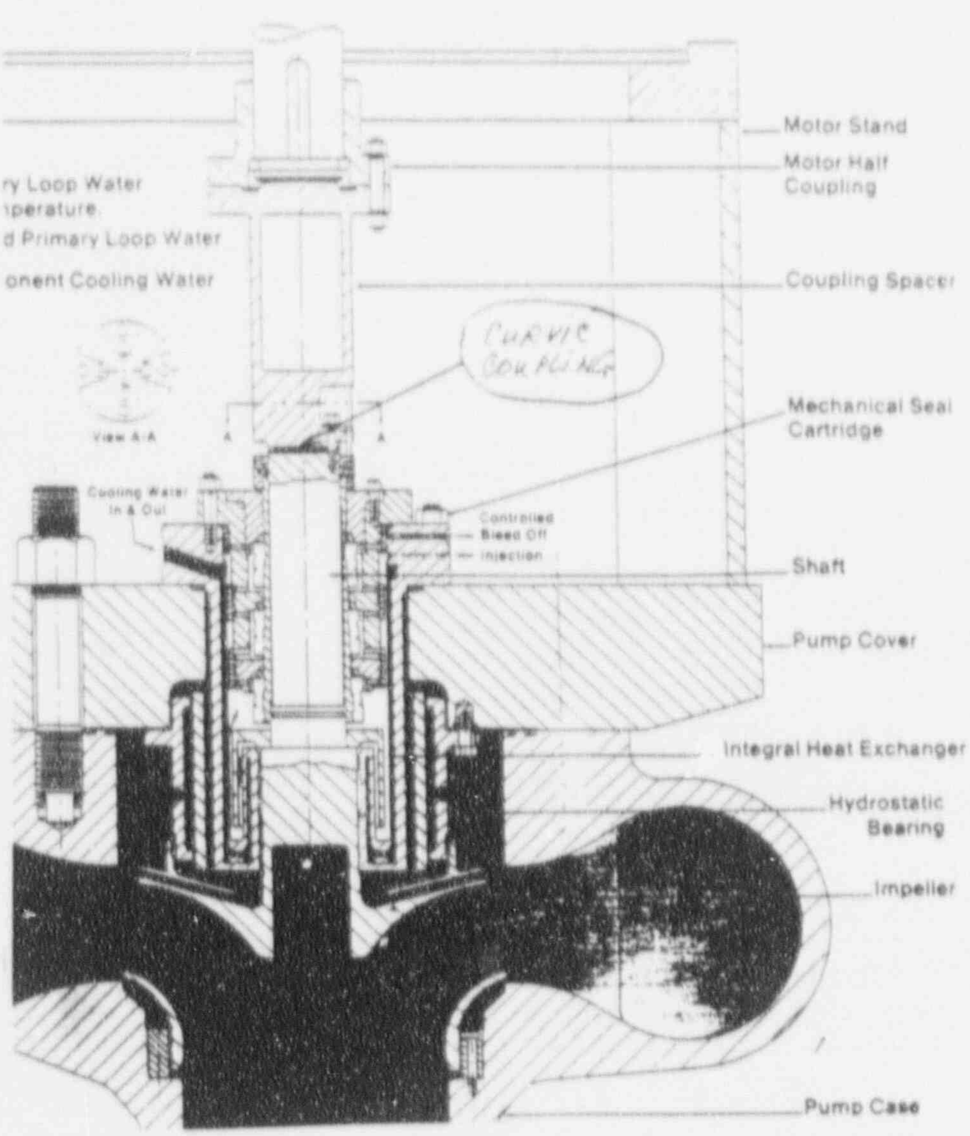


Figure 8.8

NES&L DEPARTMENT
CALCULATION SHEET

ICCN NO./ PRELIM. CCN NO.	PAGE OF

CCN CONVERSION
CCN NO. CCN -

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-250

Subject See Title Sheet Sheet No. 38

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	D. KAPICH	11/07/91	J.G.	11/8/91					

Curvic Dimensions

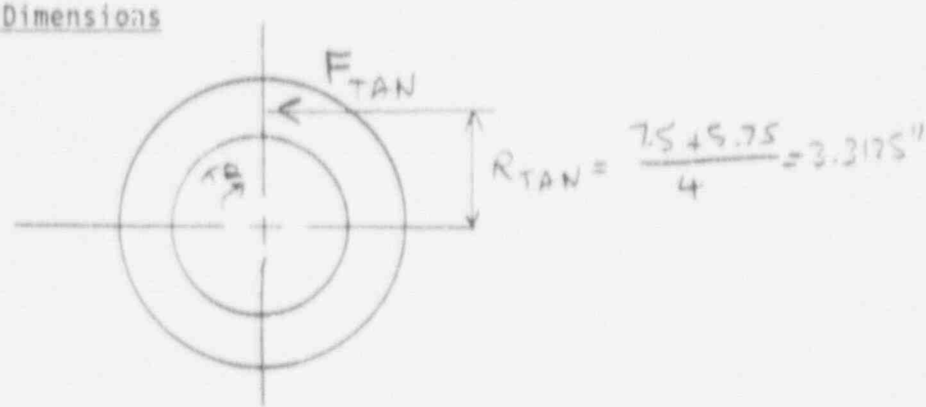


Figure 8.9

F_{TAN} is Total Force Acting on Curvic Teeth.

About ½ of the curvic perimeter is occupied by teeth from each side.

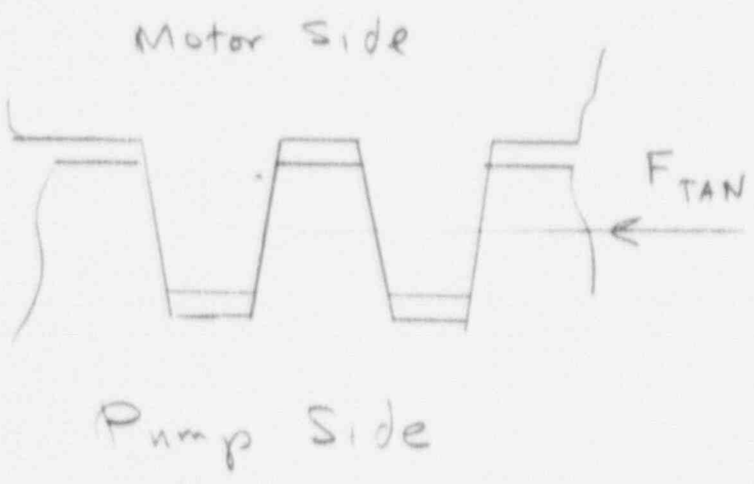


Figure 8.10

Approximate crossectional shear area of each teeth side,

NES&L DEPARTMENT

CALCULATION SHEET

ICCN NO./ PRELIM. CCN NO.	PAGE OF
CCN CONVERSION CCN NO. CCN -	

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-250

Subject See Title Sheet Sheet No. 39

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	D. KAPICH	11/07/91	J G	11/8/91					

Total annulus area = $\left(\frac{7.5^2 - 5.75^2}{4}\right)\pi = 18.2 \text{ in}^2$

$A_{shear} = \frac{18.2}{2} = 9.1 \text{ in}^2$

Per Reference: S23-922-157

"RCP Pump Manual"

Pump Side Material:

ASTM 351-Gr-CF 3A

Motor Side Material:

ASTM 182-Gr F6

Sn = 70 ksi

Ultimate Shear Strength = $\frac{70}{2} = 35$ ksi

Now, the F_{TAN} can be calculated, at the point of curvic teeth failure,

$F_{TAN} = A_{SH} \cdot S_{SH} = 9.105 \cdot 35{,}000$

F_{TAN} = 318,700 lbs.

Torque at Failure,

$T_{QF} = F_{TAN} \cdot R_{TAN} = 318{,}700 \times 3.2125$

= 1,055,693 in. lb.

Now, apply the torque T_{QF} to the flywheel keys, the shear forces acting on 2 keys is,

$F_{SH} = T_Q / 2 R_F = \frac{1055693}{2 \times 15.69}$

$F_{SH} = 33642$ lb

SCE 26-426 NEW 4/90

NES&L DEPARTMENT

CALCULATION SHEET

ICCN NO./ PRELIM. CCN NO.	PAGE OF

CCN CONVERSION
CCN NO. CCN -

Project or DCP/MMP SONGS 2&3 Calc No. M-DSC-250

Subject See Title Sheet Sheet No. 40

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	D. KAPICH	11/07/91	J. G	11/12/91					

Each flywheel key has shear area,

$$A_{SH} = 0.75 \times 7.90 = \underline{5.925 \text{ in}^2}$$

Keys shear stress,

$$S_{SH} = \frac{33642}{5.925} = 5678 \text{ ksi}$$

$$\text{Hoop stress in the flywheel} = \frac{33642}{7.9 \times 0.375}$$

$$= 11356 \text{ psi}$$

Assuming normal speed conditions, it follows that:

Maximum hoop stress at the bore = 11.356 + 16.0 + 3.9 = 31.3 ksi

Where stresses due to rotation and interference fit have been included (seismic loads were excluded).

Since crack growth evaluation was performed for maximum stress of 32.7 ksi (see Table 8.1), this case is enveloped by the results of Subsection 8.3. There will not be crack growth under rotor seizure conditions.

8.5 Key Loading Due to Motor Start-Up

The maximum angular acceleration during motor start up was calculated using the motor speed vs. time data, Table 8.3. (Table 8.3 is based on References 8 and 9)

Table 8.3

Time (Seconds)	Speed (rpm)
0.5	200
4.8	590
6.0	790
7.0	932
8.0	1109
8.4	1132

The angular acceleration = 41.9 rad/sec^2 at T = 0.5 sec.

= 10.1 rad/sec^2 at T = 8 sec.

The corresponding key load can be calculated based on the methodology described in Section 4, or by applying a simple ratio to the results of Section 8.1.

Key Load	=	22.6 ksi	at t = 0.5 sec.
	=	5.5 ksi	at t = 8 sec.

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
0	W. M. EL-AKILY	11/07/91	[illegible]	11/8/91					

Maximum tangential stress is calculated based on the actual flywheel speed using equation (4) as follows:

Tangential stress due to interference fit

= 7.09 ksi at 200 rpm

= 3.35 ksi at 1180 rpm

Rotating disk stress = 0.5 ksi at 200 rpm

= 16. ksi at 1180 rpm

Maximum total tangential stress = 22.6 + 0.5 + 7.09

= 30.2 ksi, at 0.5 sec.

Maximum total tangential stress = 3.35 + 16 + 5.5

= 24.9 ksi, at 8 sec.

Both cases above are enveloped by the analyzed overspeed condition since the maximum tangential stress in that case is 32.7 ksi.