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PURPOSE 1

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.

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2 RESULTS/CONCLUSIONS

The stress intensity factor, $K_{\rm L}$, 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 = KIC = 4-7 (See Section 8)

Where K_{ic} is the critical stress intensity for the flywheel material at the operating temperature (=220 ksi/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.

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ASSUMPTIONS 2

- The dominant stress components in the flywheel are the 3.1 tangential stress (σ_r) and the radial stress (σ_r) . The axial stress component (σ_r) 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 (zdirection) is only 2.5% of the total tangential stress.
- The flywheel is keyed to the eight spider arms by two axial 3.2 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.
- The tangential stress is of primary concern in the fracture 3.4 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 s :e radial stress is smaller than the tangengial stress.

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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):



15.5" <r < 41" (Rederence 1)

where

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| (b) Interference Fit Stresses (AR) The stress in the flywheel is due interference fit between the flywheel spider arws. The stress is a function interface pressure P, which is a function and the initial interference AR. It was calculated in Reference 1 that $D_{\pm} = \begin{cases} 1.334 P_{s} & (a \pm 1180 rp) \\ 0.334 P_{s} & (a \pm 1500 rp) \end{cases}$ where (Reference 1), $C \geq 920$ psi (a \pm 118) | |
| interference fit between the flywheel spider arms. The stress is a function interface pressure P, which is a function and the initial interference AR. It was calculated in Reference 1 that $OZ = \begin{cases} 1.334 P_s & (at 1180 TP) \\ 0.334 P_s & (at 1500 TP) \\ 0.34 P_s & (at 1500 TP) \\ 0.34 P_s$ | to the |
| $\sigma_{\overline{z}} = \begin{cases} 1.334 P_s & (at 1180 rp) \\ 0.334 P_s & (at 1500 rp) \\ where (Reference 1), \\ 0.2920 psi (at 118) \end{cases}$ | and the n of the ion of W |
| Where (Keserence 1), C2920 bsi (at 118 | m) m) |
| (s(max) = { 850 psi (at 15) | orpm) orpm) |
| (c) <u>Key Loading</u> The torque (T.) due to the deceleration o | f the PCI |
| pump is calculated as follows: $T_{Q} = \left(\frac{d\omega}{dF}\right) I_{P}$ | |
| This torque is transmitted to the through the axial keys, which resul tangential load acting on the flywhee axial key. This load (F _{KEY}) is calcu follows: | flywheel ts in a at the lated as |
| Frey = - | (3) |
| where is assumed that one key transmitting the coast down deceleration to the flywheel. (See Section 3). | is only n torque |
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(d) Seismic Loading

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Seismic loads were calculated based on the following acceleration components: (See Section 5) $A_{H} = 2.5 \text{ g}$

 $A_V = 3.59$ Tangential stress due to horizontal acceleration is given by: (Reference 1)



where A = T (a-b).

Bending stress due to vertical acceleration is calculated as follows:

total distributed load (w) = $\frac{m}{\pi(b^2a^2)}(A+g)$ = $\frac{m}{\pi(b^2a^2)}(3\cdot s+1)$

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

$$\sigma_{\overline{t}}(\max) = \frac{3W}{4\nu' t^2} \left[(b^2 a^2) \left[(4b^4 (\nu' + 1)) \log \left(\frac{b}{a} \right) + 4a^2 b^2 + a^4 (\nu' - 1) - b^4 (\nu' + 3) \right]$$
where $\nu' = \frac{1}{12} = \frac{1}{2 \cdot 3} = 3 \cdot 33$

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

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| | as | (Refer This of: Of: expl | rence 5). $F_r = \omega^2 r_c$ radial for $= \frac{F_r}{2(b-aired)}$ | The rate a res a t n F | dial force, sults in ta | F, is giv | en by: stress (5) | |

Figure 4.1 Stress due to Vibratory Motion

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

- σ (total) = σ (rotating disk stress) +
 - ø (interference fit stress) +
 - ø (key loading stress) +
 - σ (seismic) +
 - e (vibratory motion) (6)

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

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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

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The computer program PCCRACK was used to perform the analysis, and calculate the stress intensity factor (K_1) . Based on the calculated K_1 , a comparison was made with the critical stress intensity factor of the flywheel material (K_{1c}) to calculate the safety factor.

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



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| | <u>- Ro</u> | Mass density (p) Yield Strength Ultimate Strength Critical Stress i <u>tational Speed</u> Design Overspeed Normal Speed | - 0.000735 (490.8 1b) - 85 ksi - 105 ksi ntensity fac (Reference - 1500 rpm (w = 157) - 1180 rpm (w = 123) | <pre>lb, sec²/in⁴ //ft³) ctor (K_{IC}) - 220 1) .1 rad/sec.) (1200 rpm used .6 rad/sec.)</pre> | ksi√in I conservat | ively) | | |
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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) (1) | <u>∉_t-norma (ksi)</u> 16.0 | g _t -overspeed (ksi) 25.9 |
|----------------------------|--|---|
| (2) | 11.5 | 18.6 |
| (3) | 9.1 | 14.7 |
| (4) | 7.3 | 11.7 |
| (5) | 5.5 | 8.9 |

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(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) | ø _t -norma (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 |

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(c) Keyway Loading

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Per Reference 1, the keyway dimensions are:

Keyway Width = 0.750 in. K:yway 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 RCF 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:

$$p = \frac{1}{2}\pi b^*$$

for a circular plute with rudius b

Multiplying by the mass density $\frac{f'}{G}$ and flywheel thickness t,

is the growity acceleration. 0

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To calculate $\frac{d\omega}{dE}$, 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 $\frac{\partial \omega}{\partial E}$ with sufficient accuracy.

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

 $\frac{d\omega}{dE} = 84 \left(\frac{27}{60}\right) = 8.796 \text{ rod/sec}^2$

It follows that,

Since at full pump speed the shrink pressure at the flywheel bore is very minimal, it is assumed that the entire inertia torque (T_{o}) 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

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(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),

a. = 0.4 ksi

Overspeed conditions (N=1500 rpm),

e, = 0.8 ksi

The tangential stress due to the horizontal component of acceleration (A_x) 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.



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Flywheel radial force,

Assume design speed = 1500 rpm

 $\omega = \frac{2\pi x_{1500}}{50} = 157.1$ rad/sec FR = mrw2 = 6467 1b 1 FR VFR Figure 8.4



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The total tangential stress is given by equation $\boldsymbol{\delta}$.

It is summarized in Table 8.1 below:

Table 8.1

Total Tangential Stress Distribution

| Location | Total Tangential Stress, ø, (ksi) | | | | | | |
|------------------|-----------------------------------|-------------------------------------|--|--|--|--|--|
| (see Figure 8.1) | 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 | | | | | |

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8.2 Crack Growth Evaluation

inclusion is because it as an

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 $(K_{\rm I})$ versus crack depth (d), are plotted in Figure 8.7. These results are also listed in Table 8.2

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Numerical Results 8.3

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Stress intensity factors are given for different crack depths, O<d<3", in Table 8.2. Safety factors can be calculated based on the values of K_1 (from Table 8.2) and the critical stress intensity factor Kic, as follows:

$$F = \frac{\kappa_{zc}}{\kappa_{\tau}}$$

where

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

(a) %* Crack

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

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

(b) Keyway depth + 1/8" crack

In this case, $d = 0.47 + 0.125 = 0.595^*$

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(c) Crack depth equals twice the keyway depth

In this case, d = 0.94"

SF = 220 = 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 = $100 \times 50 \times 10^{-6}$

= 0.005"



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| CRACK | | -STRESS | INTENSI | TY FACTOR- | c ASE | 775-* c | A (2 (2) |) | |
| CRACK | CASE(1) DESIGN | -STRESS CASE NORMAL | INTENSI (2) | TY FACTOR- | CASE | о м | A(2 (2) |) | |
| CRACK SIZE 0.0600 | CASE(1) DESIGN 14.805 | -STRESS CASE NORMAL 11.325 | INTENSI (2) | TY FACTOR- CF+CY - SIZE | CASE DESIGN | (1) c N | A(2 (2) ORMAL - 761 |) | |
| CRACK | CASE(() DESIGN 14.805 20.928 25.621 | STRESS CASE NORMAL 11.325 16.006 19.589 | INTENS) (2) | TY FACTOR- CF+CY S ZE 1.5600 1.6200 | CASE DESIGN 74.708 76.098 | (1) (N 56 57 | A (2 (2) DR MAL . 761 . 801 |) | |
| CRACK SIZE 0.0600 0.1200 0.1800 0.2400 | CASE(1) DESIGN 14.805 20.928 25.621 29.573 | STRESS CASE NORMAL 11.325 16.006 19.589 22.605 | INTENS) | 1.5600 1.6800 1.6800 | CASE DESIGN 74.708 76.098 77.62 26.799 | (1) (N 56 57 58 | A (2 (2) 0 R M AL. . 761 . 801 . 820 | > | |
| CRACK SIZE 0.0600 0.1200 0.1800 0.2400 0.3000 | CASE(1) DESIGN 14.805 20.928 25.621 29.573 33.050 | STRESS CASE NORMAL 11.325 16.006 19.589 22.605 25.255 | INTENSI (2) | TY FACTOR- CF+CY 5 Z.E 1.5600 1.6200 1.6800 1.7400 1.8000 | CASE OESIGN 74.708 76.098 77.462 78.799 80.112 | (1) (N 56 57 58 59 60 | A (2 (2) 0 R M AL. .761 .801 .821 .820 .800 | > | |
| CRACK SIZE 0.0600 0.1200 0.1800 0.2400 0.3000 0.3600 | CASE(1) DESIGN 14.805 20.928 25.621 29.573 33.050 36.190 | STRESS CASE NORMAL 11.325 16.006 19.589 22.605 25.255 27.647 | INTENSI (2) | TY FACTOR- CF+CY 5 ZE 1.5600 1.6800 1.7400 1.8000 1.8600 | CASE OESIGN 74.708 76.098 77.462 78.799 80.112 51.402 | (1) C N 56 59 60 61 | A (2 (2) 0R MAL. .761 .801 .820 .800 .762 | > | |
| CRACK SIZE 0.0600 0.1200 0.1800 0.2400 0.3000 0.3600 0.4200 | CASE() DESIGN 14.805 20.928 25.621 29.573 33.050 36.190 39.073 41.754 | STRESS CASE NORMAL 11.325 16.006 19.589 22.605 25.255 27.647 29.842 31.860 | INTENS) (2) | TY FACTOR- CF+CY 5 ZE 1.5600 1.6800 1.6800 1.7400 1.8000 1.8600 1.9200 | CASE DESIGN 74.708 76.098 77.462 78.799 80.112 81.402 82.669 | (1) C 56 59 60 61 62 | A (2 (2) 0 R M AL. .761 .801 .821 .820 .800 .762 .706 | > | |
| CRACK SIZE 0.0600 0.1200 0.1800 0.2400 0.3000 0.3600 0.4200 0.4800 0.5400 | CASE() DESIGN 14.805 20.928 25.621 29.573 33.050 36.190 39.073 41.754 44.268 | STRESS CASE NORMAL 11.325 16.006 19.589 22.605 25.255 27.647 29.842 31.880 33.791 | INTENS) (2) | TY FACTOR- CF+CY 51ZE 1.5600 1.6800 1.6800 1.7400 1.8600 1.8600 1.9200 1.9800 | CASE DESIGN 74.708 76.098 77.462 76.799 80.112 81.402 82.669 83.914 | (1) C 56 57 59 61 62 62 | A (2 (2) 0 R.M.AL. .761 .801 .821 .820 .800 .762 .706 .633 | > | |
| CRACK SIZE 0.0600 0.1200 0.1800 0.2400 0.3000 0.3600 0.4200 0.4800 0.5400 0.5400 0.56000 | CASE() DESIGN 14.805 20.928 25.621 29.573 33.050 36.190 39.073 41.754 64.268 46.644 | STRESS CASE NORMAL 11.325 16.006 19.589 22.605 25.255 27.647 29.842 31.880 33.791 35.594 | INTENS) (2) | TY FACTOR- (1) 5600 1.5600 1.6800 1.6800 1.7400 1.8000 1.8600 1.9800 2.0400 | CASE DESIGN 74.708 76.098 77.462 78.799 80.112 51.402 82.669 83.914 85.140 85.140 | (1) V 567 599 603 603 603 603 | A (2 (2) 0 R.M.AL. .761 .801 .821 .820 .800 .762 .765 .633 .545 .441 | > | |
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| CRACK SIZE 0.0600 0.1200 0.1600 0.2400 0.3000 0.3600 0.3600 0.4800 0.5400 0.5400 0.6600 0.7200 0.7800 | CASE() DESIGN 14.605 20.928 25.621 29.573 33.050 36.190 39.073 41.754 44.268 46.644 48.900 51.053 53.116 | STRESS CASE NORMAL 11.325 16.006 19.589 22.605 25.255 27.647 29.842 31.880 33.791 35.594 37.306 38.938 40.500 | INTENS) (L) | TY FACTOR- (F+CK) 5;ZE 1.5600 1.6800 1.6800 1.7400 1.8600 1.9200 1.9800 2.0400 2.1600 2.2200 2.2800 | CASE CESIGN 74.708 76.098 77.462 78.799 80.112 51.402 82.669 83.914 85.140 86.346 85.140 86.346 87.533 88.702 89.854 | (1) N 567 599 601 661 661 661 661 661 661 661 661 661 | A (2 (2) 0 R.M.AL. .761 .801 .820 .762 .762 .762 .763 .545 .633 .545 .441 .322 7.190 8.044 | > | |
| CRACK SIZE 0.0600 0.1200 0.1800 0.2400 0.3000 0.3600 0.3600 0.4800 0.4800 0.5400 0.6600 0.6600 0.7200 0.7800 0.7800 0.8400 | CASE DESIGN 14.605 20.928 25.621 29.573 33.050 36.190 39.073 41.754 44.268 46.644 48.900 51.053 53.116 55.098 57.008 | STRESS CASE NORMAL 11.325 16.006 19.589 22.605 25.255 27.647 29.842 31.880 33.791 35.594 37.306 38.938 40.500 42.000 | INTENSI (2) | TY FACTOR- (F+CK) 5,ZE 1.5600 1.6800 1.6800 1.7400 1.8600 1.9200 1.9800 2.0400 2.1600 2.1600 2.2200 2.2800 2.3400 | CASE CESIGN 74.708 76.098 77.462 78.799 80.112 81.402 82.669 83.914 85.140 85.140 85.146 85.346 85.346 85.346 85.346 85.346 85.354 90.989 | (1) N 55789 550 55789 550 55789 550 5578 550 552 550 552 550 552 550 552 550 552 550 550 | A (F (2 0 R M AL .761 .801 .820 .800 .762 .762 .633 .633 .633 .633 .633 .644 .322 7.190 8.044 8.884 | > | |
| CRACK SIZE 0.0600 0.1200 0.1800 0.2400 0.3000 0.3600 0.4200 0.4200 0.4800 0.5400 0.6600 0.7200 0.7800 0.7800 0.96-0 | CASE DESIGN 14.605 20.928 25.621 29.573 33.050 36.190 39.073 41.754 44.268 46.644 48.900 51.053 53.116 55.098 57.008 58.853 | STRESS CASE NORMAL 11.325 16.006 19.589 22.255 27.647 29.842 31.880 33.791 35.594 37.306 38.938 40.500 43.444 44.838 | INTENSI (2) | TY FACTOR- (F+CK) 5,ZE 1.5600 1.6800 1.6800 1.7400 1.8600 1.9200 1.9800 1.9800 2.0400 2.1000 2.1600 2.1600 2.2200 2.2800 2.3400 2.4000 | CASE CESIGN 74.708 76.098 77.462 78.799 80.112 81.402 82.659 83.914 85.140 85.140 85.140 85.346 85.346 87.533 88.702 89.854 90.989 92.108 | (1) N 567 599 601 661 661 661 661 | A (F (2 0R MAL .761 .801 .820 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .764 .820 .764 .820 .764 .820 .762 .762 .764 .820 .762 .764 .820 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .820 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .762 .764 .764 .765 .762 .765 .762 .765 .7555 .755 .755 .755 .755 .755 .755 .755 .755 | > | |
| CRACK SIZE 0.0600 0.1200 0.1800 0.2400 0.3000 0.3600 0.4200 0.4200 0.4800 0.5400 0.6600 0.6600 0.7200 0.7800 0.7800 0.7800 0.9850 1.0200 | CASE() DESIGN 14.805 20.928 25.621 29.573 33.050 36.190 39.073 41.754 44.268 46.644 48.900 51.053 53.116 55.098 57.008 58.853 60.639 | STRESS CASE NORMAL 11.325 16.006 19.589 22.255 27.647 29.842 31.880 33.791 35.594 37.306 38.938 40.2000 42.000 43.444 44.838 46.186 | INTENSI (2) | TY FACTOR- (F+CK) 5,ZE 1.5600 1.6200 1.6800 1.7400 1.8600 1.9200 1.9800 1.9800 1.9800 2.0400 2.1000 2.1600 2.2200 2.2800 2.3400 2.4600 2.4600 2.4600 | CASE CESIGN 74.708 76.098 77.462 78.799 80.112 81.402 82.659 83.914 85.160 86.346 87.533 88.702 89.854 90.989 92.108 93.212 94.201 | (1) N 567 599 601 661 661 661 661 661 661 661 661 661 | A (F (2 0R MAL .761 .801 .820 .762 .762 .762 .765 .765 .765 .765 .765 .765 .765 .706 .765 .706 .722 .7190 .725 .7190 .725 .735 | > | |
| CRACK SIZE 0.0600 0.1200 0.1800 0.2400 0.3000 0.3600 0.4200 0.4800 0.5400 0.6600 0.6600 0.7200 0.7800 0.8400 0.9000 0.95_0 1.0200 1.0800 | CASE() DESIGN 14.805 20.928 25.621 29.573 33.050 36.190 39.073 41.754 44.268 46.644 48.900 51.053 53.116 55.098 57.008 58.853 60.639 62.371 | STRESS CASE NORMAL 11.325 16.006 19.589 22.665 25.255 27.647 29.842 31.880 33.791 35.594 37.306 38.938 40.500 42.000 43.444 44.838 46.186 47.492 | INTENS) (2) | TY FACTOR- (F+CK) 5,ZE 1.5600 1.6200 1.6800 1.7400 1.8600 1.9800 2.0400 2.1000 2.1600 2.2200 2.2200 2.2800 2.34000 2.4600 2.5200 2.5800 | CASE CESIGN 74.708 76.098 77.462 78.799 80.112 81.402 82.694 83.914 85.140 86.346 87.533 88.702 89.854 90.989 92.108 93.212 94.301 95.531 | (1) N 5678905556565665666666666666666666666666666 | A (F (2) 0R MAL .761 .801 .820 .820 .762 .762 .765 .7555 .755 .755 .755 .755 .755 .755 .755 .755 | > | |
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| CRACK SIZE 0.0600 0.1200 0.1800 0.2400 0.3600 0.3600 0.4200 0.4800 0.4800 0.5400 0.6600 0.6600 0.7200 0.7800 0.7800 0.7800 0.9000 0.9850 1.0200 1.0800 1.1400 1.2000 | CASE() DESIGN 14.805 20.928 25.621 29.573 33.050 36.190 39.073 41.754 44.268 46.644 48.900 51.053 53.116 55.098 57.008 58.853 60.639 62.371 64.053 65.689 67.283 | STRESS CASE NORMAL 11.325 16.006 19.589 22.605 25.255 27.647 29.842 31.880 33.791 35.594 37.306 38.0500 42.000 43.444 44.838 46.186 47.492 48.759 9.991 51.190 | INTENS) | TY FACTOR- 5 Z E 1.5600 1.6200 1.6200 1.6800 1.7400 1.8000 1.9800 2.0400 2.1000 2.1000 2.1000 2.1600 2.2200 2.2800 2.34000 2.4000 2.4000 2.5800 2.5800 2.5800 2.7000 | CASE CESIGN 74.708 76.098 77.462 78.799 80.112 81.402 83.914 85.140 86.346 87.533 88.702 89.854 90.989 92.108 93.212 93.212 93.212 93.212 94.301 95.531 96.905 | (1) N 5678905556666666666666666666666666666666666 | A (F (2) 0 R MAL .761 .801 .820 .762 .765 .765 .765 .765 .765 .765 .706 .765 .706 .765 .706 | > | |
| CRACK SIZE 0.0600 0.1200 0.1800 0.2400 0.3000 0.3600 0.4200 0.4200 0.4800 0.5400 0.6600 0.6600 0.6600 0.7200 0.6600 0.7800 0.7800 0.7800 0.9000 0.95-0 1.0200 1.0200 1.0800 1.1400 1.2600 1.3200 | CASE() DESIGN 14.605 20.928 25.621 29.573 33.050 36.190 39.073 41.754 64.268 46.644 48.900 51.053 51.053 53.116 55.098 57.008 58.853 60.639 62.371 64.053 65.689 67.283 68.838 | STRESS CASE NORMAL 11.325 16.006 19.589 22.605 25.255 27.647 29.842 31.880 33.791 35.594 37.306 38.938 40.500 42.000 43.444 64.838 46.186 47.492 48.759 49.991 51.190 52.358 | INTENS) | TY FACTOR- 5 Z E 1.5600 1.6200 1.6200 1.6800 1.7400 1.8000 1.9800 2.0400 2.1000 2.1000 2.1000 2.1600 2.2200 2.3400 2.34000 2.4600 2.5200 2.5800 2.5800 2.5800 2.5800 2.6400 2.7000 2.1600 | CASE CESIGN 74.708 76.098 77.462 78.799 80.112 81.402 83.914 85.140 86.346 87.533 88.702 89.854 90.989 92.108 93.212 94.301 95.531 96.905 98.273 99.635 | (1) V 567559 66165 661 661 661 661 661 661 661 661 6 | A (F (2 0 R. MAL. .761 .801 .821 .820 .762 .705 .633 .545 .441 5.322 7.190 8.084 9.713 0.529 1.333 2.245 4.281 5.292 | > | |
| CRACK SIZE 0.0600 0.1200 0.1800 0.3000 0.3000 0.3600 0.4200 0.4200 0.4800 0.5400 0.6600 0.6600 0.6600 0.7200 0.7800 0.7800 0.7800 0.99000 0.995-0 1.0200 1.0200 1.0200 1.2600 1.3200 1.3800 | CASE() DESIGN 14.605 20.928 25.621 29.573 33.050 36.190 39.073 41.754 44.268 46.644 48.900 51.053 53.116 58.098 57.008 58.853 60.639 62.371 64.053 65.689 67.283 68.838 70.355 | STRESS CASE NORMAL 11.325 16.006 19.589 22.605 25.255 27.647 29.842 31.880 33.791 35.594 37.594 37.594 37.594 37.594 38.938 40.500 42.000 43.444 44.838 46.186 47.492 48.759 49.991 51.190 52.338 53.498 | INTENS) | TY FACTOR- 5 Z E 1.5600 1.6200 1.6200 1.6800 1.7400 1.8000 1.8000 1.9800 2.0400 2.1000 2.1000 2.1000 2.1000 2.2200 2.3400 2.3400 2.3400 2.5200 2.5800 2.5800 2.5800 2.5800 2.5800 2.6400 2.7000 2.8000 2.5800 2.6400 2.7000 2.8 | CASE CESIGN 74.708 76.098 77.462 78.799 80.112 81.402 82.669 83.914 85.140 86.346 87.533 88.702 89.854 90.954 90.955 92.108 92.108 92.108 92.108 92.108 92.108 92.212 94.301 95.531 96.905 98.273 99.635 100.990 102.339 | (1) N 567559 66165 661 661 661 661 661 661 661 661 6 | A (F (2 0 R. MAL. .761 .801 .821 .820 .762 .705 .635 .641 5.322 7.190 8.044 8.044 9.713 0.529 1.333 2.245 4.281 5.297 7.297 | > | |
| CRACK SIZE 0.0600 0.1200 0.1800 0.3000 0.3600 0.4200 0.4200 0.4800 0.4200 0.4800 0.5400 0.6600 0.6600 0.7800 0.6600 0.7800 0.7800 0.9000 0.96×0 1.0200 1.0800 1.1400 1.2600 1.3200 1.3800 1.4400 | CASE() DESIGN 14.605 20.928 25.621 29.573 33.050 36.190 39.073 41.754 44.268 46.644 48.900 51.053 53.116 55.098 57.008 58.853 60.639 62.371 64.053 65.689 67.283 68.838 70.355 71.638 | STRESS CASE NORMAL 11.325 16.006 19.589 22.605 25.255 27.647 29.842 31.880 33.791 35.596 38.938 40.500 42.000 43.444 44.838 46.186 47.492 48.759 49.991 51.190 52.358 53.498 | INTENS) | TY FACTOR- (F*CV) 51ZE 1.5600 1.6200 1.6800 1.7400 1.8600 1.7400 1.8600 1.9200 1.9800 2.0400 2.1000 2.1000 2.1000 2.1600 2.2200 2.3400 2.4600 2.5200 2.58 | CASE CESIGN 74.708 76.098 77.462 78.799 80.112 81.402 82.669 83.914 85.140 86.346 87.533 88.702 89.854 90.989 92.108 93.212 94.301 95.531 96.905 98.273 99.635 100.990 102.339 103.683 | (1) N 5678965365666666666666666666666666666666666 | A (F (2 0 R. MAL. .761 .801 .821 .800 .762 .705 .633 .545 .641 5.322 7.190 8.084 9.713 0.529 1.333 2.245 5.292 6.297 7.297 8.293 | > | |
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8.4 Postulated Pump Seizure

It is assumed that the pump impeller, or the 24" main pump bearing, seizes, resulting 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.



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

About $\ensuremath{\mathbb{W}}$ of the curvic perimeter is occupied by teeth from each side.





Approximate crossectional shear area of each teeth side,

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| | | | | 1 | | | | | |

Total annulus area = $\left(\frac{7.5^2}{4}, \frac{5.75^2}{7}\right)\pi = 18.2$ in² A shear = $\frac{18.2}{2} = 9.1$ in²

Per Reference: \$23-922-157

"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 ${\rm F}_{\rm TAN}$ can be calculated, at the point of curvic teeth failure,

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

FTAN = 318,700 1bs.

Torque at Failure,

 $T_{OF} = F_{TAN} \cdot R_{TAN} = 318,700 X 3.2125$

= 1,055,693 in. 1b.

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

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

 $F_{SH} = 33642$ 16

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Each flywheel key has shear area,

 $A_{i,j} = 0.75 \text{ X} 7.90 = 5.925 \text{ in}^2$

Keys shear stress,

Hoop stress in the flywheel

33642

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.

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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 (rpw) |
|-------------------|----------------|
| 0.5 | 200 |
| 4.8 | 590 |
| 6.0 | 790 |
| 7.0 | 932 |
| 8.0 | 1109 |
| 8.4 | 1132 |

The angular accelerateon= 41.9 rad/sec² at T = 0.5 sec.

 $= 10.1 \text{ rad/sec}^2 \text{ at } T = 8 \text{ sec.}$

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

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

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

Tangentia) 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 | + 0.1 | 5 + 7.09 |
|---------|-------|------------|--------|---|------|-------|-------------|
| | | | | | 30.2 | ksi, | at 0.5 sec. |
| Maximum | toteï | 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.