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SUBJECT: Discusses insp of reactor coolant shafts for potential fatigue cracking. Submits preliminary results of insp, comparison w/European insp results, action plan for each unit & justification for continued operation of Unit 2.

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October 21, 1987
161-00602-EEVB/JRP

Docket Nos. STN 50-528/529/530

U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Attn: Document Control Desk

Reference: Letter from J. G. Haynes, ANPP to USNRC, dated October 8, 1987, 161-00562-JGH/JRP

Dear Sirs:

Subject: Palo Verde Nuclear Generating Station (PVNGS)
Units 1, 2 and 3
Reactor Coolant Pump Shafts
File: 87-A-056-026

Our referenced letter of October 8, 1987 discussed ANPP's plan to inspect the four Unit 1 Reactor Coolant Pump shafts for potential fatigue cracking. Upon receiving initial inspection results of two of the pumps on the morning of October 15, 1987, ANPP promptly met with the NRC Resident Inspector and additionally informed NRC of the results by telecon with both the NRC's Region V and NRR. This report provides the preliminary results of this inspection, a comparison of these results with the European inspection results, the PVNGS action plan for each of the three Palo Verde Units, Justification For Continued Operation of Unit 2, the startup and operation of Unit 3, and the refueling and subsequent operation of Unit 1.

History

ANPP was recently notified by Combustion Engineering (CE) that RCPs designed and manufactured by KSB Germany have experienced fatigue cracks in the pump shafts while in operation at several European nuclear facilities. In two instances these cracks have resulted in complete shaft severance. Since the Palo Verde RCP shafts were similarly designed and manufactured by KSB Germany, an ultrasonic examination of the PVNGS Unit 1 RCP shafts was performed to determine the extent of any cracking that may have occurred.

Inspection Results

Inspection of the PVNGS Unit 1 RCPs began on October 14, 1987 using an ultrasonic technique (developed by KWU Germany). This process can detect crack indications as small as 1.8 mm deep. If the crack is at least 2.5 mm deep, an indication of length can be obtained.

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Crack indications were found in the impeller keyway region (Figure 1) in three of the four Unit 1 pumps. The most extensive crack indication was found on pump 1B which exhibited 3 indications of at least 17 mm deep and ranging up to 56 mm in length. Figure 2 provides a representation of a typical crack indication location and Table 1 provides a summary of the crack indications for each pump.

Table 1
Summary of Indications Detected

Pump Shaft	Keyway	Distance from the top of Keyway-mm	UT-Indication Length-mm	UT-Indication Depth-mm	Note
1A	0°	20	35	8	1
	180°	7	30	7	1
1B	0°	14	27	17	1
	180°	17	56	17	1
		12	42	17	1
2A	0°	-	-	-	-
	180°	22	27	9	2
2B	0°	-	-	-	-
	180°	-	-	-	-

NOTES:

1. Indication dimensions shown on this table are minimum values and identified indication could be larger.
2. Exact crack depth and length cannot be determined due to closeness of repetition signals.

Comparison With European Data

The crack indications in Unit 1 are similar in size and location to the cracks found in the European plants. The crack indications are located in the upper keyway region extending circumferentially away from the keyway as were the majority of the cracks in the European plants. The size of the crack indications found in pump 1B keyway area were larger than those previously reported by KSB.

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

KSB's evaluation of the shaft cracking that occurred on the European plants concluded the cause of crack initiation to be attributed to a combination of several factors. KSB reports that among these factors are the reduction in the shaft materials' fatigue strength caused by chrome plating, high thermal stresses induced by loss and recovery of seal injection, stress concentration near the keyway, and possible chemistry effects.

PVNGS Action Plan

The four shafts in Unit 1 will be replaced with modified shafts during the current refueling outage. The shafts will be either new modified shafts or PVNGS repaired and modified shafts. The repaired and modified shafts have either shown no indication of cracking or the cracking is within repairable limits and are acceptable as replacement shafts. The repairable limits are based on depth and location of the crack. European experience has shown that shafts repaired by grinding out the crack have not experienced any further indication of cracking.

The new modified shafts are of the same design and material as the existing shafts. The following modifications are planned for all shafts:

1. The chrome plating is removed from the shaft in the keyway area except where needed for assembling the impeller on the shaft (Figure 3).

2. An extended shaft stop seal is installed to provide a thermal barrier to the shaft keyway area (Figure 3). The impeller hub is modified and the impeller keys are shortened to accommodate the extended stop seal.

3. All step changes in the shaft diameter are radiused out to reduce the stress concentration at these areas.

These modifications are expected to provide a longer shaft life than with the existing design. In Units 2 and 3, the RCP shafts will be inspected during each Units' first refueling outage and the shafts will be repaired or replaced if determined necessary by the inspection results.

In addition to repairing/replacing the shafts with a modified design, an enhanced shaft vibration monitoring program will be implemented. Analysis of European plant RCP shaft vibration orbit data revealed shaft orbit increase over approximately a two day period until the shaft failed. PVNGS will implement a shaft vibration monitoring program to provide an early warning alert of impending shaft failure.

PVNGS Monitoring Techniques

Based on the data from an actual failure that occurred at a European facility, RCP shaft vibration (indicative of crack propagation) can be detected within a time frame which will allow for a normal plant shutdown prior to actual failure.

The PVNGS System 80 design incorporates within the Loose Parts and Vibration Monitoring System proximity probes on the RCPs to measure the shaft displacement (or vibration) in two directions (X-Y).

The current system is equipped with alarms, and the setpoints will be reduced to approximately 1.5X the baseline data and a high alarm at approximately 2X the baseline value. This is consistent with CE recommendations. Each pump will be set up with alarm setpoints based on its individual baseline data.

Justification for Continued Operation

Actual sheared shaft events which have occurred in the industry suggest a sheared shaft event is not an operationally challenging event and a normal plant shutdown following the reactor trip will occur.

In the unlikely event of a shaft failure, an RCP shaft break event with a concurrent loss of offsite power has been previously analyzed in the FSAR Section 15.3.4 (CESSAR 15.3.4.1) with acceptable results. A sheared shaft event is within bounds of the current safety analysis and does not present any additional safety concern. The analysis assumed a mechanical failure of the shaft attributable to a manufacturing defect.

The Sequence of Events for this event is very similar to that for the RCP rotor seizure analyzed in Section 15.3.3. In the case of the shaft break, a reactor trip is generated due to steam generator differential pressure within 1.2 seconds. Due to flow (impeller) coastdown this event is less severe than the seized rotor event for which a transient minimum DNBR of 0.967 occurs and no more than 0.85 percent of the fuel pins experience DNB. The resultant radiological consequences are within the guidelines of 10CFR 100.

Although significant cracking is not expected, the shaft vibration monitoring program would provide an alert to impending shaft failure with sufficient time to perform an orderly plant shutdown.

In addition to an alarm system, the following monitoring program will be conducted:

Unit 2

- Until the setpoint reduction is implemented on Unit 2, readings will be taken each shift and compared to previous data for any increasing vibration trends.

- After the setpoint reduction RCP displacement readings will be taken once per day on Unit 2 and compared to previous data for any increasing vibration trends.

Units 1, 2, and 3

- If the vibration (on any channel) reaches the alarm setpoint or a continuously increasing trend is observed, the monitoring frequency will be increased to once per 4 hours unless the increase is due to instrument failure i.e., restricted to 1 channel. In addition, a detailed evaluation of the increase will be performed.

- If the vibration reaches the high alarm setpoint (2 channels - 2X baseline), an evaluation for plant shutdown based on increased shaft displacement will be performed.

- If the vibration reaches 10 mils (2 channels), an orderly plant shutdown using normal shutdown procedures will be conducted.

This monitoring program will be maintained in Unit 2 until the first refueling when the RCP Displacement Monitoring System will be modified and enhanced.

With the current system and monitoring program in place and based on the data from Germany (for the failed shaft) it is expected that an indication of shaft failure would be apparent and detectable within approximately two days of failure. This will allow sufficient time to evaluate the data and perform an orderly plant shutdown.

The Unit 1 system will be modified during the first refueling and Unit 3 will be modified except for the computer capability, prior to initial criticality. The Unit 3 computer capability will be added in the future.

The modification will include the addition of an additional sensor on each RCP for a phase reference. This sensor as well as the existing X and Y sensors will be monitored with a computerized system with the ability to detect very small deviations in vibration. This system will increase the accuracy and the available warning time to at least 3-5 days prior to shaft failure.

The Unit 2 RCP shafts could be expected to experience shaft crack indications to a lesser degree than the Unit 1 pumps by the time the Unit is shutdown in February 1988 for refueling. The pumps currently have approximately 13,000 hours of run time and are projected to have approximately 16,000 hours by the refueling outage (Table 2). The Unit 1 RCPs were operated for approximately 20,500 hours. The Unit 1 hours include more times at cold operating condition which induces higher stress levels than normal hot conditions. The Unit 1 RCPs have experienced four loss of seal injection events, which induces additional thermal stresses on the shafts, while the Unit 2 pumps experienced only one such event.

It is likely that repetitive and cyclic stresses are major contributors to the propagation of cracks, once formed. Based on the fact that Unit 2 will have accumulated significantly fewer hours of pump operation than Unit 1 and was subjected to fewer transients (such as pump starts/stops and thermal transients), the Unit 2 pump shafts have experienced less cyclic stresses which could promote propagation of shaft cracks than Unit 1.

In light of the information presented in the Justification for Continued Operation and based on KSB pump operating data from over 21 similar pump designs in both German plants and at PVNGS, no failures are expected to occur during Unit 3 cycle 1 operation.

Unit 3 cycle 1 is scheduled for 18 months in duration which will result in approximately 13,000 - 14,000 pump hours. In addition, approximately 2,000 hours per pump have been accumulated due to pre and post core hot functional testing. Thus, it is anticipated that the RCPs will have accumulated approximately 15,000 - 16,000 hours of run time at the end of cycle 1.

Table 2
Hours of Operation Cycle 1

Unit 1*	20,500
Unit 2**	16,000
Unit 3**	15,000 - 16,000

* Approximate
** Anticipated

[illegible]

As stated earlier, the Unit 3 shafts will be inspected during the first refueling outage. This decision is based on the fact that no problems are expected during cycle 1 and the added benefit gained from additional data from Unit 1 cycle 2, Unit 2 cycle 1 and additional German experience.

In conclusion, our efforts to date indicate that Reactor Coolant Pump shaft failure is not a significant safety concern based on our accident analysis and the operating experience in Europe. Therefore, the continued operation of PVNGS Units 1, 2 and 3 will not be harmful to the health and safety of the public.

Should you have any questions please call.

Very truly yours,

E. E. Van Brunt

E. E. Van Brunt, Jr.
Executive Vice President
Arizona Nuclear Power Project

EEVB/JRP/jle
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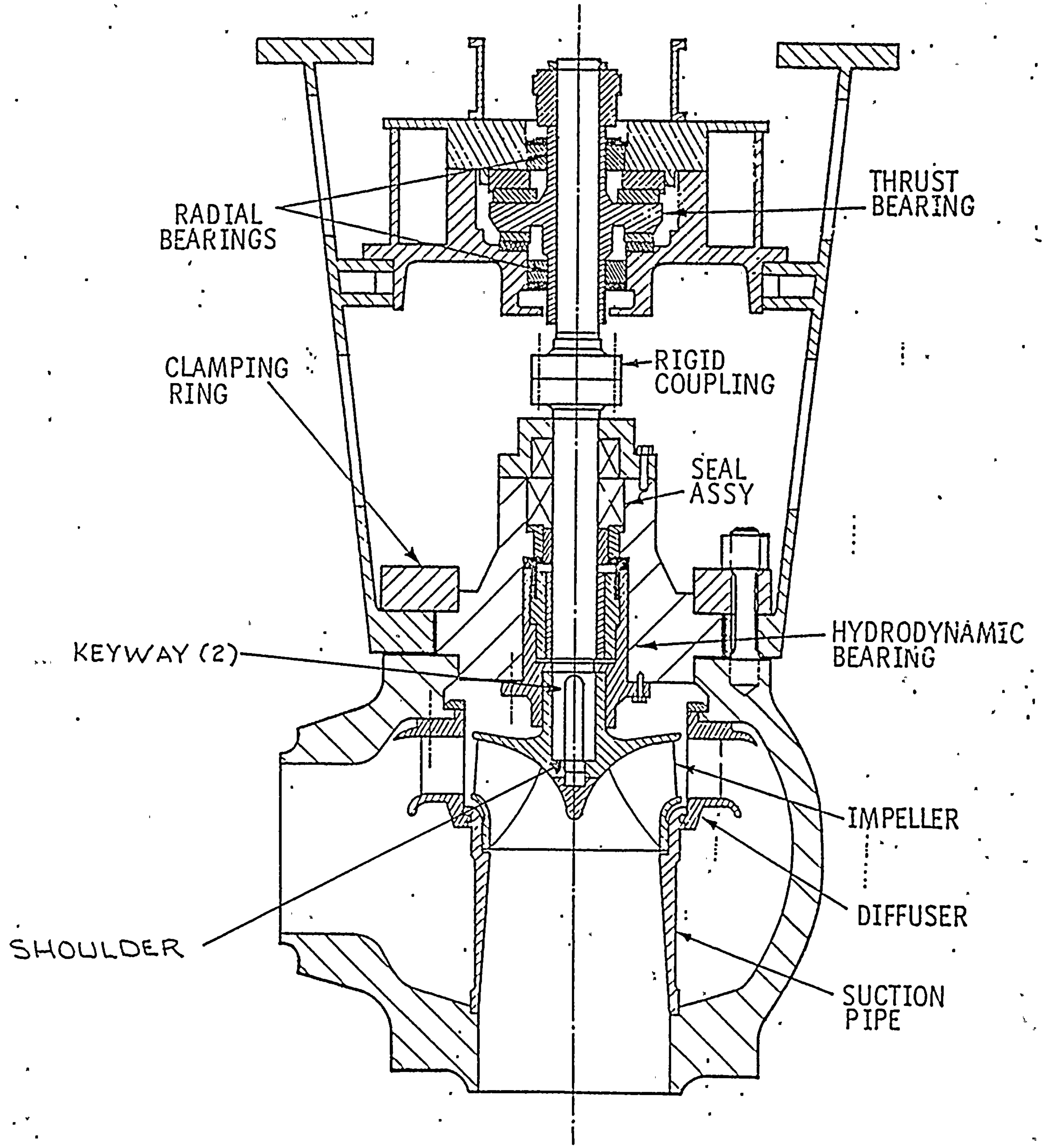
FIGURE 1



C-E - KSB PUMP DESIGN

FIGURE 2
TYPICAL CRACK INDICATION

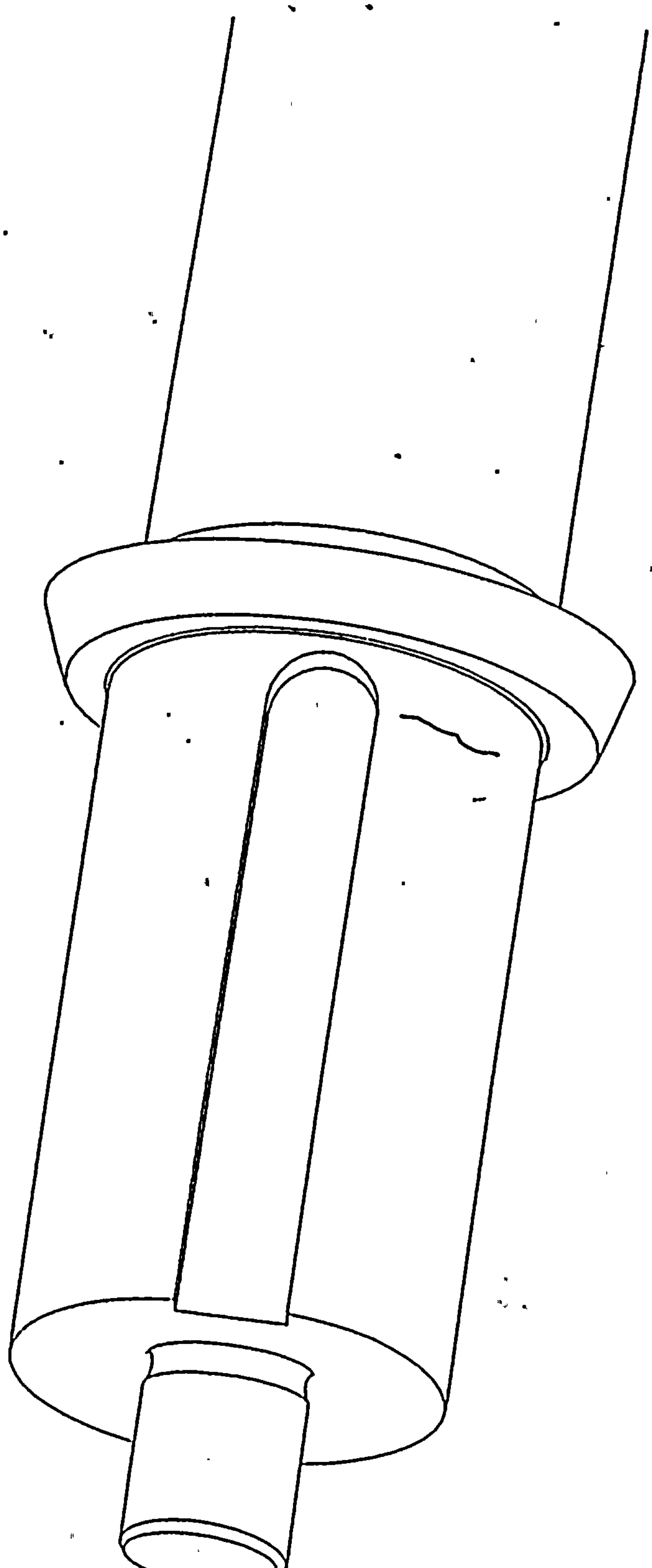


FIGURE 2.1
TYPICAL KEYWAY DIMENSIONS

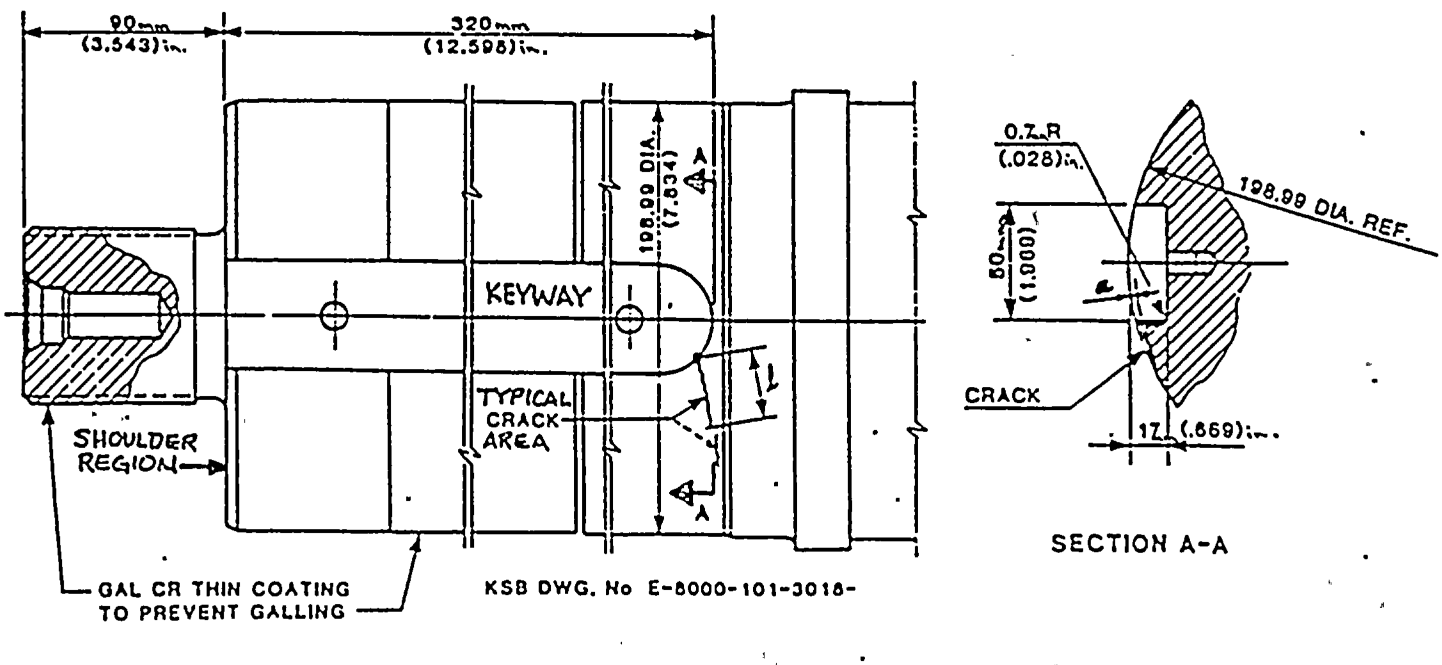


FIGURE 3 – SHAFT MODIFICATIONS