Critical Item List

Subsystem\Item No.\Part No.: HPFTP/AT\B300\4700000
Functional Assy: Turbine Section 02
Prepared by: D.F. Clark
Approved by: A.J. Slone
CIL Item: 0203
Page: 63
Issue Date: October 28, 1986
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CIL Item Code: 0203
FMEA Item Code: 0203
Function: Drive pump
Subsystem\Item No.\Part No: HPFTP/AT\B300\4700000

Analyst: D.F. Clark
Approved by: A.J. Slone
Rev. No.:
Rev. Date: April 16, 2001
Effectivity:
Hazard Ref.: See Listings Below

Operating Phase	Failure Mode, Description and Effect	Criticality

Operating Phase:
s,m,c

Failure Mode:
Loss of torque carrying capability.

Criticality:
1

Failure Cause(s)

A. f/n 043 Fracture through the splines, cooling holes, or loaded shoulder of the Disk & Shaft Set due to vibrations, thermal growth, material/mfg. defect, overspeed, rub, or loss of cooling.

B. f/n 032, 033 & 034 Fracture of the splines of the impellers, due to vibration, thermals, contamination, or material/mfg. defects.

Hazard Ref:

A) D1S/A/M/C (AT): 1A1.9.2.1.1, 1A1.9.2.1.2, 1A1.9.2.2, 1A1.9.2.3, 1A2.1.1, 1A2.1.2, 1A2.3, 1A2.6

B) D1S/A/M/C (AT): 1A1.9.2.1.1, 1A1.9.2.1.2, 1A1.9.2.3, 2A4, 2A5, 1A1.9.1.1, 2A1.1, 2A1.2, 2A2, 2A3

Failure Effect:
Loss of disk load would cause over speed, burst, and case penetration, with fire and explosion.

System:
Uncontained failure

Mission/Vehicle:
Loss of vehicle

Redundancy Screens:
Does not apply since it is a single point failure

Find Number Find Name	Design Considerations
f/n 043 Disk/Shaft Set	FAILURE CAUSE A: Fracture through the splines, cooling holes, or loaded shoulder of the Disk & Shaft Set due to vibrations, thermal growth, material/mfg. defect, overspeed, rub, or loss of cooling. The turbopump rotor is supported by a one-piece disk/shaft. The disk/shaft is made of an IN-100 (PWA-SP 1074) forging for its' strength and low cycle fatigue properties. The shaft portion includes the roller bearing bore diameter, piloting diameters for all the rotating parts, the splines which drive the impellers, and the supply holes for the boretube/ball bearing coolant. The Disk and Shaft Set (FN 043) is comprised of the disk/shaft (FN 043-01) and the pump end ball bearing (PEBB) inner race sleeve (FN 043-02) which is assembled onto the shaft for finish machining. The inner race sleeve provides the bore diameter for the PEBB inner race. The shaft contains 3 splines which transmit torque to the impellers. The Turbine Disk and Shaft (FN 043-01) is a single piece part consisting of a shaft with an integral, solid bore, disk at one end. The shaft section of the part is assembled primarily with pump end components such as the impellers, bearings, boretube and the pump to turbine seal packages. The disk, on the other hand, is mainly a turbine component. Assembled on it are the turbine blades, blade spacers and dampers, blade retainers and coverplate. These components are used to extract energy from the main turbine flow path and transfer it, in the form of torque, to the shaft to turn the impellers and to pump liquid hydrogen up to the high pressures required for engine operation. On the OD of the disk are 50 blade attachment lugs and two retainer grooves. Each stage contains 50 blades with the 2nd stage aligned directly behind the 1st stage circumferentially. Between the two stages of blades, contained within each of the attachment lug slots, are two blade spacers that axially position the blades and hold the blade dampers. A circumferential groove is machined on the ID of the inlet side of the lugs to form a hook which holds the front retainer ring. This ring, which resembles a piston ring, is snapped into place after all the components are assembled into the lugs and prevents them from coming out the end of the lugs during assembly and shipping. Another groove is machined on the OD of the exit side of the lugs which forms hooks for the rear retaining ring to hold the blade retainer in place. The ring, also similar to a piston ring, is trapped under the blade retainer, which has a matching groove, and is radially supported by it during operation. All the axial load from the blade and spacer stack is transferred through the blade retainer and rear retaining ring into these hooks on the rear end of the lugs. Directly under these hooks, a 1° conical snap is machined to position and retain the disk coverplate. The Coverplate (FN 166) shields the disk from direct scrubbing of the lift-off seal flow and provides insulating dead space pockets between the parts. This allows the temperature from the hotter rim to soak down into the body of the disk through conduction providing a more gradual thermal gradient from bore to rim similar to what the flow mixtures accomplish on the inlet side of the disk. The coverplate, also machined from a PWA-SP 1074 (IN 100) forging, is a disk/plate type structure with a hole in the center and a zigzag OD that provides piloting and support for the part. It is held in place axially by the main shaft stack with the same load split that goes through the roller bearing inner race and lift-off seal (LOS) runner, controlled by an axial spring. On the disk side of the coverplate are 8 radiused vent slots that allow drying and pressure relief of the middle dead cavity. The disk/shaft is a fracture critical part and meets all the requirements of the SSME ATD fracture control plan FR-19793-5. DVS 4.1.2.9 Structural design analyses to verify adequate rotor life are complete. The results are documented in FR-20715-04 and -05 and FR-20716-05 with the VCR in FR-20715-103 and -104. The rotordynamic analysis concluded that; 1) All fundamental rotor bending mode critical speeds have adequate margin over max rotor speed. 2) Forced response analysis predicts small relative deflections throughout the operating speed range. 3) No occurrence of discrete nonsynchronous rotor whirl. 4) Transient analysis predicts a rotor dynamically sound design. 5) Worse case flight maneuvers result in low relative deflections. DVS 4.1.4.1.7.1 Rig load test of the tie bolt to verify stretch prediction has been completed. The results are documented in FR-20715-23 and -24 with the VCR in FR-20715-103 and -104. DVS 4.1.4.1.7.2 Turbine spin test of a fully bladed strain gaged disk has been completed. The results are documented in FR-20715-24 with the VCR in FR-20715-103 and -104. DVS 4.1.4.1.7.3 Turbine disk burst test to verify mechanical integrity has been completed. The results are documented in FR-20715-24 with the VCR in FR-20715-103 and -104. DVS 4.1.4.1.7.4 Turbine disk vibration test to verify margin has been completed. It was verified at a higher level. The results are documented in FR-20904-262 with the VCR in 20715-103 and -104. DVS 4.1.4.2.3.1 Modal tests on an unbladed turbine rotor have been completed. The results are documented in FR-20716-23A and -23B with the VCR in FR-20715-120. DVS 4.1.4.2.4.1 Tests have been completed on a turbine bladed rotor instrumented for dynamic response. The results are included in VCR document FR-20715-104.
f/n 032, 033, 034 Impellers Stg. 1, 2, 3	FAILURE CAUSE B: Fracture of the splines of the impellers, due to vibration, thermals, contamination, or material/mfg. defects. The pump incorporates three Impeller stages (FN's 032, 033 & 034) to increase the pressure of the liquid hydrogen supplied to the powerhead. The Impellers are machined from PWA-SP 1240 A110 ELI Titanium forgings for its cryo toughness, specific strength and low density. All three stages are shrouded designs using six full length blades, six mid length splitters and twelve short splitters to do the work. Each impeller is piloted to the shaft and to its adjacent impeller with tight radial snaps and

Find Number Find Name	Design Considerations

each has a unique spline feature carrying the torque for assembly foolproofing. The first and second stages incorporate lab seal lands for controlling leakage flows and pressures. The third stage acts as a double acting thrust piston. Tip seals at the discharge, a corner seal at the inlet and a face seal on the back side, vary front and back face pressures with shaft position.To improve HCF margin, all three impellers are media finished and shot peened and highly stressed corners are rounded. Individual impeller balance is achieved by material removal from lowly stressed areas of a front and rear balance plane. The 2nd impeller additionally accommodates two 180° counter weights for pump-end rotor stack balance. Material is removed from the segments for balance and each segment has a different size alignment lug to foolproof assembly.

All three impellers are fracture critical parts and meet all the requirements of the SSME ATD fracture control plan FR-19793-5.

DVS 4.1.2.3 Pump hydrodynamics analysis to verify pump performance is complete. The results are documented in FR-20709-01 and -02 with the VCR in FR-20712-27 and FR-23231-107.

DVS 4.1.4.1.3.1 Strain gaged spin tests for the pump impellers are complete. The results are documented in FR-20715-25, FR-20715-27 and FR-20715-28 for impellers 1,2 and 3 respectively. The VCR is in FR-20715-102.

DVS 4.1.4.1.3.2 Spin burst tests for the pump impellers are complete. The results are documented in FR-20715-25, FR-20715-27 and FR-20715-28 for impellers 1,2 and 3 respectively. The VCR is in FR-20715-102.

DVS 4.1.4.1.3.3 Vibration tests to determine resonant frequencies for impeller 1 are complete. Vibration tests are not required for Impellers 2 and 3. The results are documented in FR-20716-18 with the VCR in FR-20715-102.

DVS 4.1.4.1.3.4 Adequate impeller rub margin has been substantiated by lack of wear during engine level testing at SSC. No report to be issued.

DVS 4.1.4.1.3.6 Photoelastic test stress analysis of first stage impeller has been completed. The results are documented in FR-20715-20 with the VCR in FR-20715-102.

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Functional Assy: Turbine Section 02 | **Approved by:** A.J. Slone | **Issue Date:** October 28, 1986

Failure Mode: Loss of torque carrying capability. | **CIL Item:** 0203 | **Rev. Date:** April 16, 2001

Inspection and Test

Possible Causes	Significant Charactertistics	Inspection and Test	Document Ref
Failure Cause A f/n 043 Shaft Set	Material Integrity	Material integrity of shaft (f/n 043-01-1) is verified per drawing and specification requirements	PWA-SP 1074
		Material integrity of nut (f/n 043-02-1) is verified per drawing & specification requirements	PWA-SP 1074
		Shot peening of shaft (f/n 043-01)(2 pl) is verified per specification requirement	AMS 2430
	Inspection	3rd Stage impeller pump end pilot (f/n 043-01) diameter is verified per drawing requirement	
		1st Stage impeller pilot (f/n 043-01) diameter runout is verified per drawing requirement	
		2nd Stage impeller spline (f/n 043-01) data is verified per drawing requirement	
		Lift-off seal ring pilot (f/n 043-01) diameter runout is verified per drawing requirement	
		Lift-off seal ring pilot (f/n 043-01) diameter is verified per drawing requirement	
		Roller bearing journal (f/n 043-01) diameter runout is verified per drawing requirement	
		Roller bearing journal (f/n 043-01) diameter is verified per drawing requirement	
		1st Stage impeller pilot (f/n 043-01) diameter is verified per drawing requirement	
		3rd Stage impeller pump end pilot (f/n 043-01) diameter runout is verified per drawing requirement	
		3rd Stage impeller turbine end pilot (f/n 043-01) diameter runout is verified per drawing requirement	
		3rd Stage impeller turbine end pilot (f/n 043-01) diameter is verified per drawing requirement	
		Pump end inverted nut (f/n 043-02) diameter is verified per drawing requirement	
		1st Stage impeller spline (f/n 043-01) data is verified per drawing requirement	

Inspection and Test

Possible Causes	Significant Charactertistics	Inspection and Test	Document Ref
		2nd Stage impeller pilot (f/n 043-01) diameter is verified per drawing requirements	
		3rd Stage impeller spline (f/n 043-01) data is verified per drawing requirement	
		Blade root slot (f/n 043-01) profile is verified per drawing requirement	
		2nd Stage impeller pilot (f/n 043-01) diameter runout is verified per drawing requirement	
	Raw Material	Sonic- per- QAD (nut) (f/n 043-02)	SP-SIM 1
		Sonic- per- QAD (shaft) (f/n 043-01)	SP-SIM 1
	Finished Material	FPI- per- QAD (shaft set) (f/n 043)	SP-FPM Master
		ECI- per- QAD (shaft set) (f/n 043)	SP-ECM Master
		FPI- per- QAD (shaft set (f/n 043) - area nut is machined at assy)	SP-FPM Master
		FPI- per- QAD (nut) (f/n 043-02)	SP-FPM Master
	Assembly Integrity	Penetrant inspect per DAR	PW0260
		Part seating (spanner nut (f/n 043-02)) is verified per REI	REI 012
	Recycled Hardware	FPI- per- PWA-SP 36187 (Nut) (f/n 043-02)	PWA-SP 36187 & SP-FPM Master
		FPI- per- PWA-SP 36187 (Shaft Set) (f/n 043)	PWA-SP 36187 & SP-FPM Master
Failure Cause a f/n 166 Cover,Turbine	Material Integrity	Material integrity is verified per drawing and specification requirements	PWA-SP 1074
		Shot peen is verified per specification requirements	AMS 2430
	Raw Material	Sonic- per- QAD	SP-SIM 1
	Finished Material	FPI- per- QAD	SP-FPM Master

Inspection and Test

Possible Causes	Significant Charactertistics	Inspection and Test	Document Ref
		ECI- per- QAD	SP-ECM Master
	Assembly Integrity	Part seating is verified per REI	REI 012
	Recycled Hardware	FPI- per- PWA-SP 36187	PWA-SP 36187 & SP-FPM Master
Failure Cause B f/n 032 Impeller,Stage 1	Material integrity	Material integrity is verified per specification requirements	PWA-SP 1240
	Inspection	Blade leading edge thickness verified per drawing requirements	
		Turbine end pilot diameter is verified per drawing requirements	
		Pump end pilot diameter is verified per drawing requirements	
		Spline data is verified per drawing requirements	
		Shroud thickness is verified per drawing requirements	
	Raw Material	Sonic- per- QAD	SP-SIM 1
	Finished Material	ECI- per- QAD	SP-ECM Master
		Proof spin test is verified per specification requirements	REI 018
		FPI- per- QAD	SP-FPM Master
	Assembly Integrity	Part seating is verified per REI	REI 012
		Maximum temperature limit if part is subjected to heat to facilitate assembly is verified per REI	REI 012
	Recycled Hardware	FPI- per- PWA-SP 36187	PWA-SP 36187 & SP-FPM Master
Failure Cause B f/n 033 Impeller,Stage 2	Material integrity	Material integrity is verified per specification requirements	PWA-SP 1240

Inspection and Test

Possible Causes	Significant Charactertistics	Inspection and Test	Document Ref
	Inspection	Blade leading edge thickness verified per drawing requirements	
		Turbine end pilot diameter is verified per drawing requirements	
		Pump end inside diameter is verified per drawing requirements	
		Spline data ia verified per drawing requirements	
		1st Stage pilot diameter is verified per drawing requirements	
		Shroud thickness is verified per drawing requirements	
	Raw Material	Sonic- per- QAD	SP-SIM 1
	Finished Material	FPI- per- QAD	SP-FPM Master
		Proof spin test is verified per specification requirements	REI 018
		ECI- per- QAD	SP-ECM Master
	Assembly Integrity	Part seating is verified per REI	REI 012
		Maximum temperature limit if part is subjected to heat to facilitate assembly is verified per REI	REI 012
	Recycled Hardware	FPI- per- PWA-SP 36187	PWA-SP 36187 & SP-FPM Master
Failure Cause B f/n 034 Impeller,Stage 3	Material integrity	Material integrity is verified per specification requirements	PWA-SP 1240
	Inspection	2nd Stage pilot diameter is verified per drawing requirements	
		Turbine end pilot diameter is verified per drawing requirements	
		Pump end inside diameter is verified per drawing requirements	
		Spline data is verified per drawing requirements	

Inspection and Test

Possible Causes	Significant Charactertistics	Inspection and Test	Document Ref
		Shroud thickness is verified per drawing requirements	
		Blade leading edge thickness are verified per drawing requirements	
	Raw Material	Sonic- per- QAD	SP-SIM 1
	Finished Material	Proof spin test is verified per specification requirements	REI 018
		ECI- per- QAD	SP-ECM Master
		FPI- per- QAD	SP-FPM Master
	Assembly Integrity	Part alignment onto shaft is verified per Assembly Drawing requirements	
		Maximum temperature limit if part is subjected to heat to facilitate assembly is verified per REI	REI 012
		Part seating is verified per REI	REI 012
	Recycled Hardware	FPI- per- PWA-SP 36187	PWA-SP 36187 & SP-FPM Master
All Cause	Assembly Integrity	Cleanliness control of all parts during final assembly are verified per specification requirement	PWA-SP 80
		Shipping container; cleanliness control of closures, desiccant material and GN2 purge are verified per specification requirements	PWA-SP 80, MIL-D-3464, MIL-P-27410C
	Acceptance	Acceptance test will be conducted as required by contract, to demonstrate specified performance.	FR24542
	Maintenance	Shaft rotation torque check is verified per OMRSD.	OMRSD V41BS0.060