CH-Francis "Canyon" FC-40/100 Vertical Francis Turbine

Operation and Maintenance Manual: Copper Canyon Dam, Units 1–3

Document	CH-DOC-OM-0101
Revision	4
Date	2026-08-14
Applies to	CH-FR-1987-0042 (Unit 1), CH-FR-1987-0043 (Unit 2), CH-FR-1989-0051 (Unit 3)
Owner	Cromley Hydraulics, Product Engineering, Francis Line
Status	Issued to Desert River Water & Power Authority (DRWPA)

Revision history

Rev	Date	Change
1	1987-05-20	First issue, Units 1 and 2
2	1989-11-02	Unit 3 added
3	2014-06-30	Rehabilitation programme: new governor interface, updated limits, oil specification
4	2026-08-14	Chapter 9 added: CH monitoring PLC retrofit (dual-element RTDs, vibration, HPU and cooling monitoring, MQTT data). Alarm tables and troubleshooting updated. Maintenance recommendations updated.

1 Safety and scope

This manual covers the hydraulic turbine, its guide and thrust bearings, the bearing lubrication and cooling systems, the governor hydraulic power unit (HPU) and the CH monitoring PLC. The generator, excitation, unit protection and the plant control system are supplied by others and are referenced only where they interface with CH equipment.

> *Work on the unit requires the owner's lock-out / tag-out procedure: intake gate and inlet valve closed and locked, penstock drained where required, HPU depressurised, brakes applied. Never enter the spiral case, headcover pit or draft tube unless the owner's permit is in place.*

The owner (DRWPA) remains responsible for unit protection settings. The values in this manual are CH recommendations.

2 Design data

Item	Value
Type	Vertical-shaft Francis turbine, CH-Francis "Canyon" FC-40/100
Rated output (generator terminals)	40 MW
Maximum continuous output	42 MW (105 %), only at net head of 100 m or more
Rated net head	100 m (permissible range 80–115 m)
Rated speed	300 rpm (50 Hz, 10 pole pairs); runner frequency 1X = 5 Hz
Runaway speed	approx. 2.0 × rated speed
Runner	13 blades; blade-pass frequency 65 Hz
Distributor	20 wicket gates, two servomotors (A and B) on a common regulating ring
Flow	approx. 43.5 m^3/s at best efficiency (87 % gate, 100 m); 50 m^3/s at 100 % gate and 100 m
Peak efficiency	93 % at 87 % gate, rated head

Item	Value
Minimum stable load	3 MW
Shaft line	Generator rotor with upper and lower guide bearings, thrust bearing in the upper bracket, turbine guide bearing in the headcover
Shaft seal	Water-lubricated carbon segment seal, seal water from the cooling water system
Inlet valve	Butterfly valve DN 3,200, hydraulically opened, counterweight closed

3 Operating range and the rough zone

A Francis turbine runs smoothly near its best efficiency point. At part load (roughly 40–80 % of best-efficiency flow) a rotating vortex forms in the draft tube cone. This **vortex rope** causes pressure pulsations at about **0.28 × runner frequency (approx. 1.4 Hz on this machine)**, sub-synchronous shaft vibration, power swings and, over time, fatigue cracking of the draft tube cone and cavitation erosion of the runner.

The **rough zone** of the FC-40/100 is **35 % to 70 % wicket-gate opening**, with the strongest rope near 55 %. In MW it depends on net head:

Net head (m)	Rough zone (MW)	Maximum output (MW)
80	6.8 – 21.2	31.1
90	8.3 – 25.6	37.4
100	9.8 – 30.1	42.0
106	10.7 – 32.9	42.0
115	12.1 – 37.2	42.0

CH requirements for operation in the rough zone:

- Pass through the rough zone only while ramping. Do not hold a setpoint inside it.
- The plant controller's rough-zone table shall not be bypassed without a documented engineering assessment.
- Cumulative operation inside the rough zone of more than **50 hours per year** requires a draft tube cone and runner inspection at the next outage. Owners are advised to record rough-zone hours per unit.
- Signs of rough-zone operation: draft tube pressure pulsation with a dominant frequency near 1.4 Hz, TGB shaft vibration above approx. 100 µm pp with a sub-synchronous component, headcover vibration above 2 mm/s rms, MW swings of ±1 MW.

At low head (below approx. 90 m) and at loads above 90 % gate, cavitation risk increases; see section 8.6.

4 Bearings

4.1 Arrangement

Bearing	Location	Type	Pads	Oil system	Cooling circuit
Thrust bearing	Generator upper bracket	Tilting pad, babbitt	6	Own oil pot, 1,600 L, ISO VG 68	GB
Upper guide bearing (UGB)	Generator upper bracket	Segment, babbitt	4 instrumented	Own oil pot, 350 L, ISO VG 68	GB
Lower guide bearing (LGB)	Generator lower bracket	Segment, babbitt	4 instrumented	Own oil pot, 400 L, ISO VG 68	GB
Turbine guide bearing (TGB)	Headcover	Segment, babbitt, oil bath	4 instrumented	Own oil pot, 450 L, ISO VG 68	TB (own circuit)

The thrust bearing has a high-pressure oil lift (jacking) system, used during start-up and run-down below 30 % speed.

4.2 TGB pad clearance

Design radial clearance of the TGB segments: **0.30 mm ± 0.05 mm**. A segment set tighter than 0.25 mm runs hotter (more shear heating in a thinner film) and has less margin when the oil degrades. Clearances above 0.35 mm reduce damping and raise shaft vibration. Any deviation shall be recorded on a CH concession form and the segment's temperature trended.

4.3 Normal temperatures

At rated output, cooling water inlet 10–25 °C:

Measurement	Normal range
Thrust pads	60 – 70 °C
UGB / LGB pads	55 – 66 °C
TGB pads	60 – 68 °C
Oil baths (all bearings)	45 – 58 °C
Pad-to-pad spread within one bearing	normally below 3 K; investigate above 5 K

Temperatures fall with load and rise about 0.7 K per K of cooling water inlet temperature. Pads closer to the oil inlet run slightly cooler; a fixed offset of 1–2 K between pads is normal and stable.

4.4 Temperature instrumentation

Pad 1 of every bearing carries a **dual-element Pt100**:

- **Element A** is wired to the owner's unit controller and used for unit protection.
- **Element B** is wired to the CH monitoring PLC.

All other instrumented pads carry a single-element Pt100 wired to the CH monitoring PLC only. The owner's control room therefore sees **one pad per bearing**; the CH PLC sees all pads (see chapter 9).

4.5 Bearing temperature limits

Function	Measured on	Limit	Action
CH PLC alarm H	Every pad (element B / single element)	75 °C	Investigate, see 8.1
CH PLC alarm HH	Every pad	85 °C	Reduce load, prepare controlled stop
CH PLC oil alarm	Every oil bath	65 °C	Check cooling, see 8.2
Owner alarm (recommended)	Pad 1, element A	80 °C	Per owner procedure
Owner trip (recommended)	Pad 1, element A, 5 s delay	90 °C	Emergency stop

> *Because protection acts on pad 1 only, a problem on another pad may reach high temperatures before the owner's protection responds. CH recommends that the owner brings the CH PLC pad alarms into the control room.*

5 Lubrication

5.1 Oil specification

Bearings: turbine oil ISO VG 68, rust and oxidation inhibited (R&O), new-oil TAN max. 0.10 mg KOH/g. HPU: hydraulic oil ISO VG 46, anti-wear.

5.2 Oil condition limits (bearing oil)

Parameter	Normal	Caution: resample within 30 days, find cause	Action: change oil, inspect bearing
Viscosity at 40 °C	61 – 75 cSt	±10 % from new	±15 % from new
TAN (mg KOH/g)	below 0.25	0.25 – 0.40	above 0.40
Water (ppm)	below 200	200 – 500	above 500
Tin, Sn (ppm), babbitt wear indicator	below 5	5 – 15	above 15
Iron, Fe (ppm)	below 10	10 – 25	above 25

Parameter	Normal	Caution: resample within 30 days, find cause	Action: change oil, inspect bearing
Particle count ISO 4406	17/15/12 or cleaner	18/16/13	19/17/14 or worse
Varnish potential, MPC ΔE	below 20	20 – 30	above 30

A rising tin trend together with rising TAN and MPC indicates oil oxidation and babbitt distress. Oxidised oil loses film strength; the most loaded or widest-clearance segment is affected first.

5.3 Oil change

Change bearing oil on condition (section 5.2). Without condition data, change at the latest every **36 months**.

6 Cooling water system

Cooling water is taken from the penstock through one **unit strainer** (duplex basket, manual changeover, differential pressure gauge PDI-x01) and one **total flowmeter** (owner's, FT-x01). It then splits into three circuits:

Circuit	Serves	Nominal flow	CH PLC low-flow alarm
TB	TGB oil cooler	8 L/s	below 5.6 L/s (70 %)
GB	Thrust, UGB and LGB oil coolers	12 L/s	below 8.4 L/s (70 %)
AirCoolers	Generator air coolers	60 L/s	below 42 L/s (70 %)
Total	Owner flowmeter	80 L/s	Owner alarm recommended below 56 L/s

Shaft seal water is taken downstream of the strainer (approx. 35–45 L/min). Cooling water returns to the tailrace.

Clean the strainer when the differential pressure exceeds 0.3 bar, and at least monthly during the high-silt season (spring runoff). A blocked strainer reduces **all** circuits at the same time; every bearing and the generator warm up together.

7 Governor hydraulic power unit (HPU)

Item	Value
Oil	ISO VG 46 anti-wear, sump 2,500 L
Accumulator	Air-oil, working pressure 58–63 bar
Pumps	2 × 4 L/s; lead pump on at 58 bar, off at 63 bar; lag pump on at 54 bar, off at 61 bar
Normal pump duty	5–8 starts per hour in steady operation
Servomotor stroke	approx. 40 L per full stroke; opening 15 s, closing 6 s
CH PLC alarms	Pressure below 52 bar; more than 15 starts/h; filter ΔP above 2.5 bar; sump below 55 %
Owner protection (recommended)	Start permissive 55 bar; alarm 52 bar; trip 48 bar

Rising pump starts per hour with normal gate activity indicate internal leakage or pump wear. A falling sump level with a drifting servomotor indicates an external (servomotor seal) leak.

8 Troubleshooting

8.1 Bearing pad temperature high

Always compare the pad with its neighbours, its oil bath, the other bearings and the cooling water before acting.

Pattern	Likely cause	Check
One pad rising, neighbours rising a little, oil bath rising slowly	Developing oil-film loss on that pad: clearance, oil condition, contamination, babbitt damage	Oil sample (Sn, TAN, MPC, water), pad clearance records, vibration at that bearing; reduce load
One pad changing while neighbours, oil bath and pad 1 element A stay flat	**Measurement fault**: RTD, cable, connector, terminal	Compare element A and B on pad 1; check connectors and glands (see CH-SB-2026-03); measure loop resistance

Pattern	Likely cause	Check
All pads of one bearing and its oil bath rising	Cooling circuit of that bearing, oil level, oil cooler fouling	Circuit flow, cooler outlet temperature, oil level
All bearings and generator rising together	Cooling water: strainer, valve, supply	Total flow, strainer ΔP
TGB pads warmer, with high TGB vibration and draft tube pulsation	Rough-zone operation (TGB load increases with the vortex rope)	Gate position against the rough zone table; draft tube waveform
Rise after maintenance	Clearance, alignment, oil level or wrong oil	Maintenance records

8.2 Oil bath temperature high

Check circuit flow, cooler outlet temperature (fouling), oil level and cooling water inlet temperature. A slow rise over weeks at constant load and inlet temperature points to oil cooler fouling.

8.3 Shaft vibration high

Pattern	Likely cause
1X dominant, rises with speed, stable phase	Mechanical unbalance
1X rises with gate opening rather than speed	Hydraulic unbalance (runner)
2X present, elliptical orbit	Misalignment, bearing clearance
Sub-synchronous component near 0.28 × 1X, with draft tube pulsation	Vortex rope (rough zone)
Step change at constant load	Shear pin failure, loose part
Blade-pass (13X) sidebands, 2X growth on headcover	Runner crack

Shaft vibration (shaft relative, peak-to-peak): normal 35–70 µm at full load; **alert 140 µm**, **danger 220 µm**. Headcover velocity: normal approx. 1 mm/s rms; alarm 4.5 mm/s.

8.4 Pump starts high / accumulator pressure low

See chapter 7. Compare decay rate after the pump stops: faster decay at the same gate activity means internal leakage.

8.5 Shear pin broken

A broken shear pin frees one wicket gate. The CH PLC raises the shear pin and breakaway alarms. Expect a vibration step on TGB and headcover. Do not continue to operate; stop the unit in a controlled way.

8.6 Cavitation

Cavitation increases at loads above 90 % gate, at heads far from 100 m and at low tailwater. Signs: rising high-frequency energy on the headcover accelerometer. Inspect the runner band and blades at each annual inspection; record areas and depths.

9 CH monitoring PLC (retrofit 2026)

9.1 Purpose

From 2026 every FC-40/100 is fitted with a CH monitoring PLC. It reads all bearing pad RTDs (element B on pad 1), oil temperatures and levels, cooling circuit flows, HPU pressure, pumps and filter, turbine pressures, shaft proximity probes (X/Y at UGB, LGB and TGB) with a keyphasor, a headcover accelerometer, a draft tube pressure sensor, generator stator RTDs and air gap. It copies the operating point (MW, gate, net head, speed, unit state) from the owner's system as read-only context. **It never writes into the owner's control system.**

9.2 Data

The PLC publishes to the site MQTT broker under `v1.0/CH/Fleet/DRWPA/CopperCanyon/<serial>/…`: process values every second (with `quality` and `seq`), raw vibration and pressure waveform blocks, a nameplate, alarm events and active alarms. The owner's tag names are listed in the site's interface inventory.

> *The `quality` field reports the PLC's knowledge of the signal path (GOOD, UNCERTAIN for stale context, BAD for missing context). It does **not** detect a sensor that reads wrong but plausible values. Plausibility checks (pad versus neighbours and oil bath) are recommended in the owner's analytics.*

9.3 Alarms

The PLC alarm limits are those given in sections 4.5, 6, 7 and 8.3, plus stator winding above 120 °C and minimum air gap below 10.5 mm (nominal 12.0 mm at standstill, approx. 11.6 mm running).

9.4 Installation notes

RTD extension cables to the CH PLC (pad 1 element B and pads 2..n) run from each bearing to local junction boxes (JB-x-01 upper bracket, JB-x-02 lower bracket, JB-x-04 headcover pit) and from there to the PLC cabinet. Connectors are M12, IP67 when fully mated and with the cable gland fully tightened. The headcover pit is a wet area; see service bulletin CH-SB-2026-03.

10 Maintenance recommendations

Task	Interval	Notes
Bearing oil sample (all pots)	Quarterly	Sn, Fe, TAN, water, viscosity, particle count, MPC; trend per pot
Bearing oil change	On condition, at the latest 36 months	Flush pot when MPC above 30
Unit strainer cleaning	On ΔP above 0.3 bar; monthly in high-silt season	Record ΔP before and after
Oil cooler inspection / cleaning	2 years or on fouling trend	
HPU oil sample	6 months	
HPU filter element	On ΔP alarm or 12 months	
Accumulator pre-charge check	12 months	
Shear pin and gate linkage inspection	Annual inspection	
Draft tube cone and runner inspection	Annual inspection	Required after more than 50 h/year in the rough zone
TGB clearance check	Major overhaul, or after any TGB temperature event	
Shaft seal segments	Annual inspection; replace on wear	Trend seal water flow and headcover sump pump starts
CH PLC: RTD connector and gland check	6 months, and after any work in wet areas	See CH-SB-2026-03

11 Contacts

Cromley Hydraulics Field Service: Lars Bergström, field service engineer for Copper Canyon Dam. Product Engineering, Francis Line, for concessions and engineering assessments.