Condition monitoring on hydraulic pumps – lessons learnt

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Agenda

1 Considerations to Condition Monitoring (CM)

2 Hydraulic Pump – functional overview and failure types

3 Studies on CM for hydraulic pumps and lessons-learnt

4 Conclusions, Questions and Discussion

1. Considerations to Condition Monitoring

- […] Condition monitoring (CM) is the process of monitoring a parameter of condition in machinery, such that a significant change is indicative of a developing failure […]

  [Z. Stramboliska, E.Rusinski, R. Moczko, Proactive Condition Monitoring of Low-Speed Machines, Springer, 2015].

- The basic understanding of condition monitoring (CM) – the main levels to be achieved by CM application:
  - **Level B:** aiming **to identify and to distinguish failures** at an early stage under operation and environmental conditions.
  - **Level A:** focusing on **predicting and forecasting the remaining useful lifetime** of the weak parts inside the equipment until major failure.

- The choice of different CM data processing and analysis approaches:
  - The **data driven** approach.

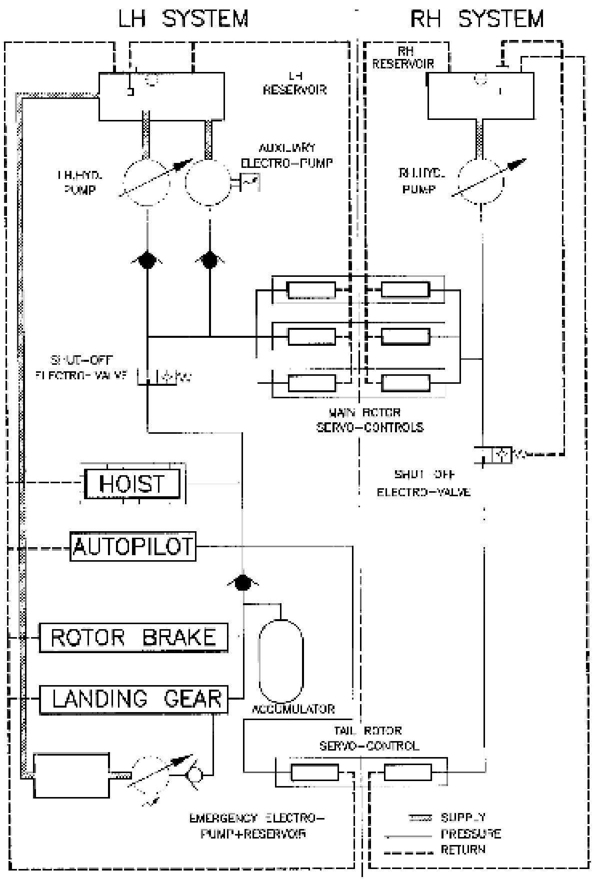
    > supports the understanding of the system physics by real happened behaviour.
  - The **physics driven** approach.

    > supports the prediction as it results from the modelled case-effect relationship.

2. Hydraulic pump – about helicopters

- External temperatures in the range of -40°C to +50°C;
- Can fly as high as 7000m;

- Pump: 1 failure per 100,000 flight hours (FH) (rate 10-5 /FH) rated "mission and safety critical"
  - ➢ At minimum 2 hydraulic pumps to fulfil safety requirement of 10e-9 /FH for medium and heavy class H/C.



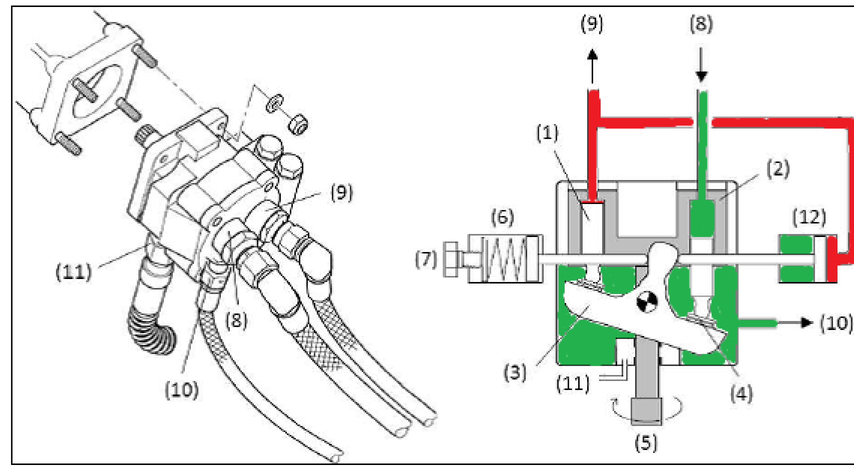
Characteristics of helicopters fleet axial piston pumps

	Flow rate (L/min)	Pressure (bar)	Weight (kg)	Max power consumption (W)
Range	8 to 60	103 to 210	1,1 to 5,6	1700 to 22000

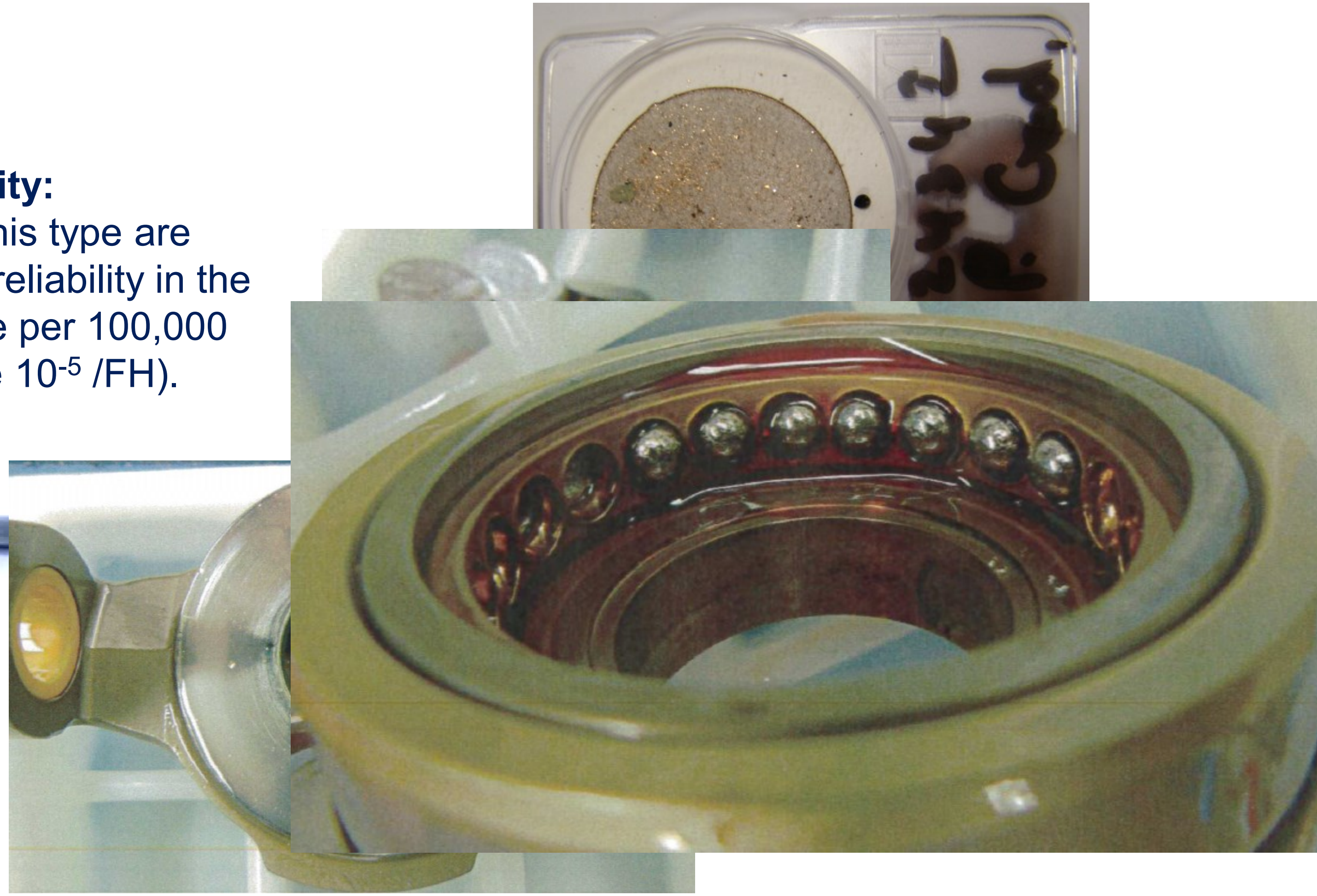
2. Hydraulic pump – functional overview

- The hydraulic pumps used in most of AH H/C fleet are axial piston machines with an internal swash plate for pressure/flow compensation.

(1)	Piston	(7)	Adjustment screw
(2)	Cylinder barrel	(8)	Suction port S (from VBR)
(3)	Hanger	(9)	Pressure port P (to VBR)
(4)	Shoe retainer plate	(10)	Case drain port CD
(5)	Splined shaft	(11)	Seal drain port SD
(6)	Spring	(12)	Pressure compensating valve



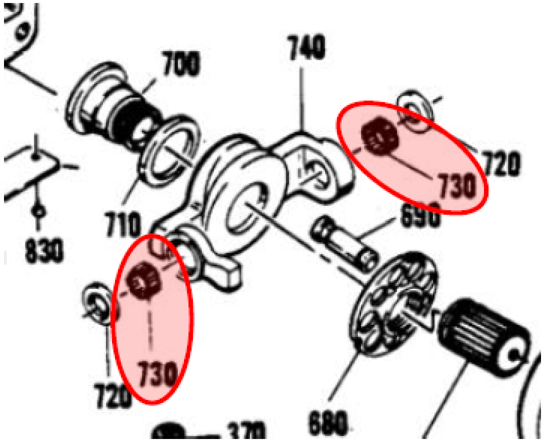
2. Hydraulic pump – failure types

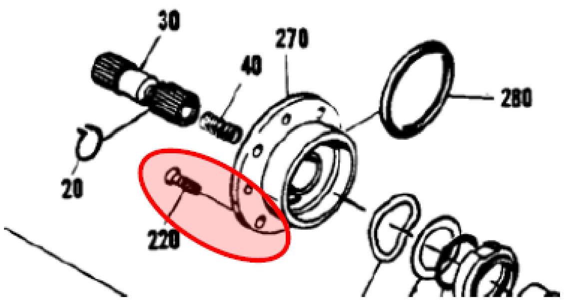


Reminder to reliability:
Hydraulic pumps of this type are considered having a reliability in the magnitude of 1 failure per 100,000 flight hours (FH) (rate 10^{-5} /FH).

2. Hydraulic pump – supplier data evaluation example

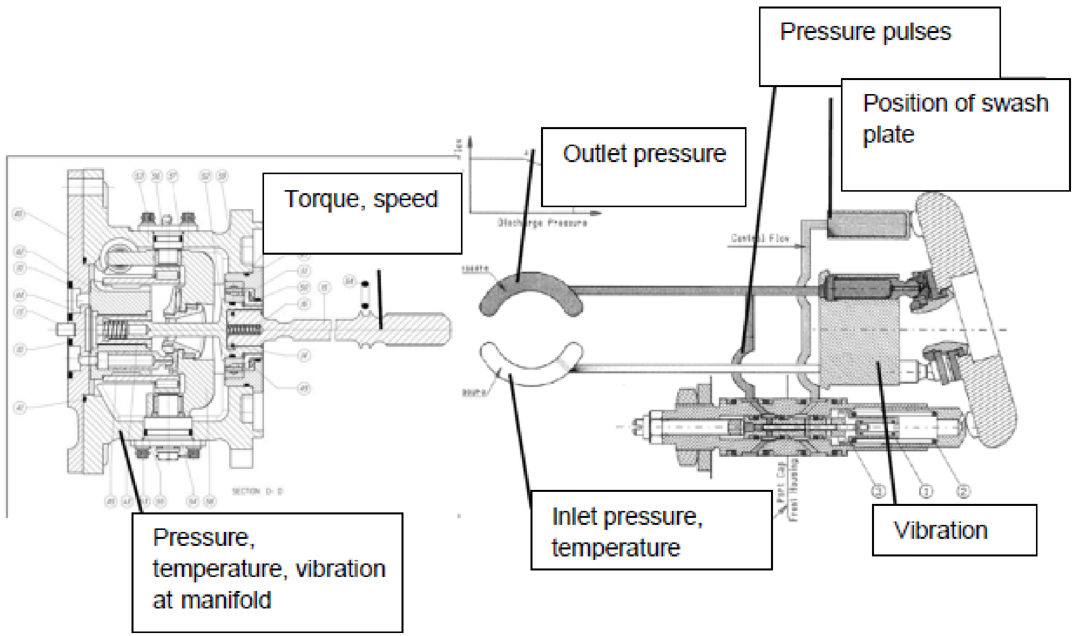
Supplier provided a list showing components affected by frequent exchange/wear during overhaul in **Qpa** (quantity per annum).
The needle bearing (730) and screws (220) seem to be the top leading items.
The pump has no TBO and is maintained "on-condition".
MTBF (mean-time-between-failure) of 13,000 to 16,000 FH (flight hours).





2. Hydraulic pump – possible sensor locations for CM

Unclassified



3. Studies on CM for hydraulic pumps and lessons learnt

- **18 studies on pump CM were reviewed from different fields (sensors, algorithms, hardware, simulation…)**

→ Pressure & temperature provide some monitoring capabilities but gives no early indication of incipient failures.

→ Test bench environment not sufficient for proof of robustness.

→ To consider common cause failures on sensors is necessary (redundancy or usage of dissimilar sensors).

→ Influence of piston wear on pump outlet flow and pressure ripple waveform.

→ There exist a lot of different ways to improve the information carried by the measured signals (FFT, wavelet transform…).

→ Pattern recognition approaches to be investigated for robustness to environmental/system changes.

→ Example of successful detection of simultaneous built-in failures by combined monitoring of outlet pressure, leakage flow rate and axial and radial vibrations.

4. Conclusions, Questions and Discussion

- Out of the learnt lessons, the following main obstacles in the process to implement CM into H/C for hydraulic pumps were identified:
  - Insufficient consideration of **environmental influences** (temperatures, vibration, noise, sensor reliability).
  - Non-availability of **correlation analysis** between in-service data and confirmed damage reports from maintenance.

- Further lessons learnt:
  - **Hardware** is needed to generate sustainable data. Pure simulation/software (→ physics driven) approach will very probably not lead to successful results.
    ➔ **Hybrid approach** of combined data and physics driven approach needed.
  - To remain at single laboratory level (one test bench) is not enough to design & test a robust CM architecture;
    ➔ the **combination of results from different benches plus real operating H/C data** will be needed.

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4. Conclusions, Questions and Discussion (2)

In-service data collection
+
Continuous improvement of CM hybrid algorithm

→ **Level B achievement**
NB : NO immediate benefit for customers

CM concept roadmap for H/C hydraulic pumps:

- Benefit analysis to validate improvement to operating costs/safety by CM concept introduction.
- Definition of the pump failures considered as main drivers for system reliability.
- Selection of a combination of limited number of sensor types and their location for failure identification.
- Definition of suitable operation event conditions for data acquisition.
- Definition and validation of a suitable simulation model.
- Establishment of an information flow process from involved MRO shops for repair/inspection result data to allow correlation with in-service obtained data.
- Constitution of an hybrid CM algorithm based on simulation data, bench test data, in-service data and MRO shop finding results.

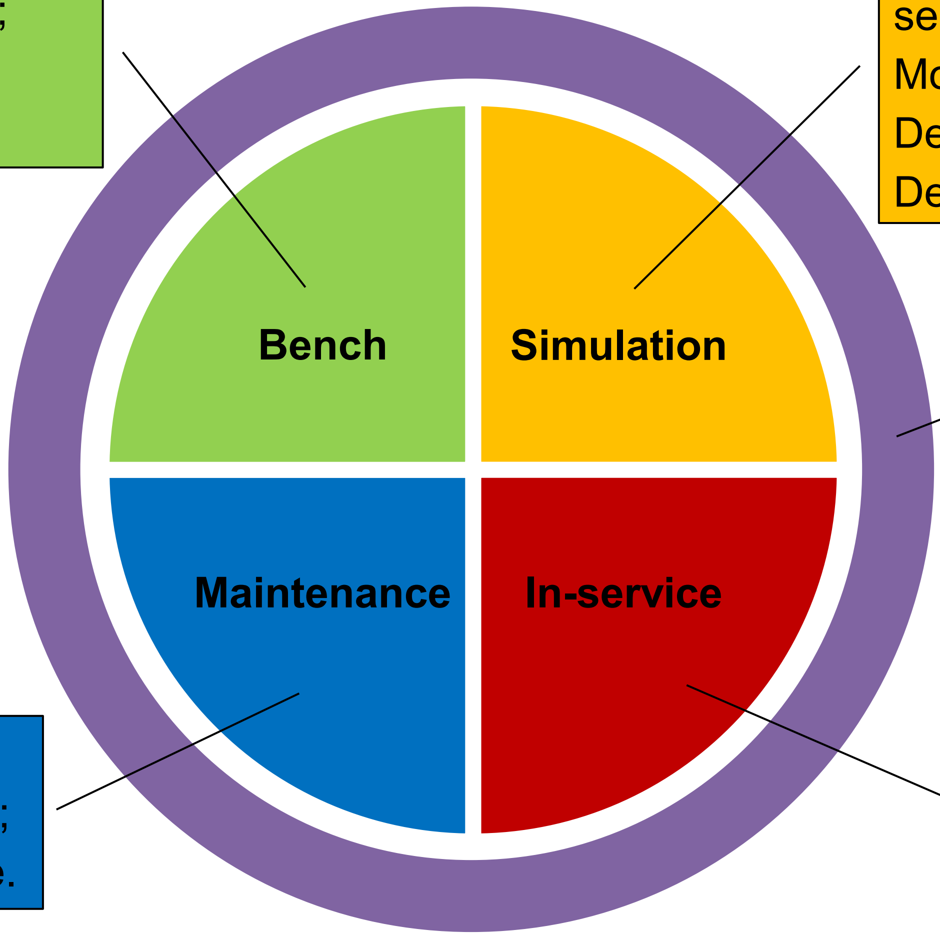
In-service data trend parameter identification → **Level A achievement** Predictive maintenance

4. Conclusions, Questions and Discussion (3)

The CM concept:

Condition data;
Data storage;
Data part of algorithm.

Modelling data from bench and in-service;
Model part of algorithm;
Definition of failure characteristic;
Definition of algorithm.



Hybrid approach;
System state changes;
Real time condition monitoring;
Real time condition prediction.

Clear failure identification;
Data storage.

Condition data;
Event based data storage.

Thank you for your attention!

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