Predictive Condition Monitoring and Maintenance for Space Propulsion

Space systems and applications have developed significantly over the decades since Sputnik. The requirements have evolved and ambitions have grown. The useful lifetime of assets in space has become longer thanks to the growing expertise, to standards established, testing and qualification procedures, and the growing database of information on the performance of assets developed and used.

The re-use of space systems used for access and return from space has evolved from the Shuttle to the recovery of Ariane 5 solid boosters, to the X38 and comparable systems in India and China, to IXV and Space Rider currently under development, to the re-use of Shepard by Blue for suborbital flights and of lower stages by SpaceX.

Equally, the lifetime of planetary probes and rovers has seen continuous improvements.

All of these evolutions rely on the condition of the systems in use and the health of the system as a whole and of its subsystems.

Condition and health monitoring is key to the extension and improvement of lifetime of assets, and is equally key to ensure that anomalies are detected early, systems are brought to safe mode and a solution be found to recover full functionality.

Predictive condition and health monitoring is the next step. Harvesting the benefits of big data processing, of artificial intelligence, prognosis targets the estimation of the remaining useful lifetime, possible upcoming failure modes, thereby improving the overall safety of the overall systema and thereby brining new possibilities for cost savings (e.g. reduced downtimes) and maintenance optimization (e.g. spare part logistics).

Industry 4.0 and digitization offer great potential for operating production facilities efficiently and cost-effectively, for example, through condition monitoring and predictive maintenance. With customized solutions, we help companies to translate theory into industrial practice and save costs.

Predictive condition and health monitoring and maintenance is based primarily on:

- Avoiding downtime and keeping downtime to a minimum
- Quickly repair or replace defective and faulty components
- Plan maintenance at optimal costs and reduce energy costs
- To reduce production costs with optimal quality

Fraunhofer ITWM, highlights that various work steps with their production-specific requirements must be taken into account:

1. **Smart Sensor Data and Digital Twin**
   The sensor data are collected, locally pre-processed and transferred to a computing unit for multivariate data analysis. For this purpose, the number of sensors has to be kept low on the one hand and on the other hand a high information content with best possible measurement quality has to be

generated to create a digital twin of the system. A design-of-experiment helps to obtain the maximum information content with a minimum number of experiments.

2. **Condition Monitoring**
   The quality analysis or monitoring of the product quality already allows first conclusions to be drawn about changes in the manufacturing process. The condition monitoring of plants allows the identification of critical events and conditions with high wear potential. Events and faults are classified and evaluated. Critical events can be eliminated immediately by a quick reaction in order to avert cost-intensive consequential damage. In addition, appropriate diagnoses of the causes are made.

3. **Anticipate Risks with Predictive Maintenance**
   Predictive Maintenance predicts risks of undesired operating states and events based on the empirical values gained from condition monitoring. These forecasts enable demand-oriented planning of service and maintenance actions to optimize plant effectiveness.

4. **Predictive Maintenance Saves Costs and Time**
   Predictive Maintenance reduces downtime and saves costs, since service technicians, spare parts and logistics are provided in a targeted manner through appropriate diagnoses. Predictive maintenance helps to plan the availability of the systems and provides information at an early stage for targeted maintenance actions while taking manufacturing, service and sales prices into account.

The work envisaged should examine the following:

- The identification of the main failure modes in satellites and launch systems and their main system that would lead to a mission failure;
- The identification of the main failure modes in propulsion test benches;
- The conceptual design of sensor architectures to monitor the health of the propulsion system – as a subset of the whole space system – and of the test bench and its subsystems;
- The design and setup of a digital twin of the propulsion system and test bench incl. data collection and pre-processing;
- The design and implementation of AI algorithms for predictive condition and maintenance.

The desired infrastructure for an experimental component to this research is:

- Data server and real-time simulator;
- Sensor and data acquisition hardware.