Condition Monitoring for hydraulic Power Units – user-oriented entry in Industry 4.0

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Abstract
One of Bosch Rexroth’s newest developments is the ABPAC power unit, which is both modular and configurable. The modular design of the ABPAC is enhanced by a self-contained Condition Monitoring System (CMS), which can also be used to retrofit existing designs. This dissertation shows how Industry 4.0-Technology provides special advantages for the diverse user profiles. Today, Hydraulic Power Units have either scheduled intervals for preventive maintenance or are repaired in case of component failures. Preventive maintenance concepts, until now, did not fully utilize the entire life expectancy of the components, causing higher maintenance costs and prolonged downtimes. Risk of unscheduled downtime forces the customer to stock an array of spare parts leading to higher inventory costs or in the event a spare is not readily available, the customer may encounter long delivery times and extended downtime. Bearing this in mind, we’ve conceived the idea of a self-contained intelligent Condition Monitoring System including a predictive maintenance concept, which is explained in the following.

KEYWORDS: Condition Monitoring, Power Unit ABPAC, predictive maintenance
1. **Industry 4.0**

Acknowledging the fact that Industry 4.0 (i4.0) is a term under ongoing development and with many aspects still being discussed, the following description serves the purpose of broadly defining the new industrial revolution: Industry 4.0, in reference to the fourth Industrial Revolution, is a growing collection of Internet of Things (IoT), which is linked to technologies utilized in an industrial context. This results in the following technological potentials /1/:

- Fusion of the physical world of production with the virtual world of information technology and the internet.
- Humans, machines, objects and systems are connected via information technologies and communicate in an optimized, real time, dynamic, and self-organized way.
- In these intelligent production systems, all branches of the value chain, including supplier to the customer, are connected across the company.
- Within the industrial production environment, individualized customer requests can be addressed in a timely manner with high-quality, higher flexibility, robustness and optimal resource allocation.

2. **Opportunities and Challenges – The new modular configurable Power Unit ABPAC**

The main task of a Hydraulic Power Unit is to generate a defined amount of hydraulic power. The amount of power is determined by a defined volume/flow, which is then delivered at a certain hydraulic pressure.

These two key parameters are the main selection criteria for a modern hydraulic system. The first step to utilizing the ABPAC configurator is to select the volume/flow and operating pressure required. With this selection, a wide range of recommended pumps and electric motors will be made available. Based on the results from step one, the applicable tank size for the power unit is defined as an output of the configurator. The oil tank is available in four sizes and in three different variations. The tank is designed according to industry standard fluid mechanics and degassing principles. The ABPAC development focused on reducing tank volume without sacrificing hydraulic power.

Furthermore, the configurator allows the user to select from a wide range of accessories and options to adapt the Hydraulic Power Unit precisely to application requirements.
This includes:

- Drip tray
- Pressure filter, return filter
- Air cooler / water cooler
- Accumulator
- Oil heater
- Level switch
- Temperature indicator
- Pressure indicator
- Aluminum profiles (mechanical fixing elements)
- Speed controlled drive units

The full spectrum provided by ABPAC is shown in the following figure (Figure 1).

**Figure 1:** Technical spectrum of ABPAC

At the end of the configuration process, the customer receives the complete product documentation: bill of material, drawings, circuit diagrams and a 3D-model as well as the pricing information for the configured unit.

The greatest advantages of the ABPAC are the reduction of quotation time and design effort, as well as the high level of technical safety in the design process.
The following figure (Figure 2) displays three of approx. 20,000 possible ABPAC-configurations and the main parts of a power unit.

![Diagram of a power unit with labeled parts: Reservoir, Electrical motor, Accumulator, Hydraulic pump, Return line filter, Cable tray, Hydraulic control system, and Mechanical fixing elements.]

**Figure 2:** Examples for configured ABPAC

3. **Focus on people as key players**

Several i4.0 technologies address the following criteria to enhance user experience and shape the digital transformation of organizations:

- Individual address and integration of employees, e.g. by adaption with regard to language, ergonomics and experience
- Flexibility with regard to place and time
- Secure, safe and intuitive human machine interaction
- Contextual information and decision support
- Personalized training and instruction
- Digital and mobile assistance

In summary, the integration of real world and virtual interfaces only provide the technological platform – the crucial step is to provide solutions that convince users and customers that this transition is essential. User-oriented development methods may help to extend the scope from the pure technical performance indicators to a holistic view on user profiles and the experience a product or service generates. The Customer Journey approach is a widely used and proven approach to analyze the touchpoints a customer has with a supplied solution. **Figure 3** provides an impression of a starting template as it is used in Bosch Rexroth innovation studies and product developments to acquire an overview of the different stakeholders within the organization of a customer. The goal is to provide an extended view on the product life cycle with a user centric aspect.
4. Condition Monitoring – how it is installed and used in ABPAC

As hardware remains a core component in an industrial context, the intelligent implementation of a cyber-physical systems concept becomes even more important. The authors refer to these kind of products - capable to realize i4.0 use-cases based on modern electronics, communication & software technology - as i4.0 (ready) components.

A pivotal question during a development process of networked products and systems is how to achieve scalability for different customer scenarios.

One exemplary use-case is applying i4.0 technologies in Condition Monitoring of subsystems, such as Hydraulic Power Units (HPU). Of course, the monitoring of several sensor signals and a diagnosis based on known cause-effect relationships would be possible with standard automation technologies. Interest to provide technology that enhances preventive maintenance capability and minimizes the need for unscheduled or demand-oriented maintenance, was the starting point for implementation of an HPU4.0.

4.1. Hardware and software architecture for Condition Monitoring

The basis for all Condition Monitoring Systems are the sensors used in the power unit to monitor the actual values and states. In ABPAC, an array of sensors can be used, i.e. pressure, temperature, fluid level, and oil particle or viscosity sensors, to name a few.
To provide our customers with a retrofit option and the full degree of freedom and control with regards to the machine and process control strategy of the new HPU platform, the ABPAC is equipped with the decentralized i4.0 control unit IndraControl FM. As an i4.0 component, this control features the Open Core Interface (OCI) and the possibility to setup a local web socket server such as the WebConnector. As shown in Figure 4, this enables the user to combine proven PLC routines with web technologies such as HTML5.

![Figure 4: Hardware and software architecture of the ABPAC Condition Monitor](image)

The realized web application generates a platform independent, use-case tailored solution for the technician on site: The HPU behaves as a local hotspot and the authorized technician can access the current and historic condition data of the HPU via a standard web browser without installing additional software. Additionally, the customer benefits from incorporated Bosch Rexroth expertise concerning the cause-effect relationships between certain measured values and component wear mechanisms.

4.2. Challenges of predictive maintenance in hydraulic power units

For maintenance personnel it is always a balancing act (see Figure 5): Do they replace components or fluid too often with prevention in mind, generating unnecessary costs as the components could still be functional or do they respond only in the event of a
machine failure, risking an unscheduled production stop with devastating costs. The cost for replacement components may only amount to a few Euros, but the cost of emergency repairs and the loss of production can quickly amount to a higher sum.

The new ABPAC from Rexroth with the decentralized condition monitoring functions, provides advanced notification of hydraulic system issues before they result in costly machine downtime. Components and hydraulic oil are changed only when necessary, which results in lower maintenance costs and increased productivity.

**Figure 5:** cost comparison of different maintenance strategies

4.3. Prediction models used in ABPAC for predictive maintenance

With the new power unit series ABPAC, Rexroth consistently relies on decentralized condition monitoring functions and predictive maintenance strategies. To implement this approach, extensive knowledge of hydraulics and a high understanding of the cause-effect relationships is required. This applies in particular for complex hydraulic systems such as Hydraulic Power Units and numerous components and technologies that must work symbiotically together.

Applying statements about the wear and tear conditions, realistic life models of all components and the entire system must be defined. Here, Rexroth leverages decades of experience in hydraulics in a wide variety of applications and environments.
Based on this, maintenance and product specialists have developed life models for components, subsystems and the hydraulic fluid, which are validated through experiments and displayed in the software.

In addition, Rexroth has integrated a cabinet-free electronic unit, containing an intelligent evaluation logic software for the new power unit series ABPAC. The data is recorded locally via a sensor node and continuously monitors the operating conditions and wear relevant criteria, comparing the measured values with the stored lifetime models. The focus lies on the hydraulic oil, the valves and the drive unit. Furthermore, the system also detects the filter contamination or the duration of use of pressure hoses and other components.

Sensors monitor continuously the output, suction, reservoir pressure, temperature, level, particles and other contamination of the hydraulic oil. Based on this information the evaluation logic observes the oil condition and makes predictions about the remaining service life. The Condition Monitoring System also counts the cycles of the valves and compares them with the nominal lifetime. According to this information, it is then possible for the maintenance personnel to schedule any necessary changes. With the help of drive data, the electronic system can calculate for example, the volumetric efficiency with the comparison of rotational speed and pressure over the period of operation, this indicator shows the wear of the pump.

The simplest way to display the above mentioned generated information, in a user friendly form is with the traffic light system, used in the ABPAC now (Figure 6). This logic shows the current state of the hydraulic oil and the components in a green, yellow or red light system. At a glance, the operator can see whether an action is needed or not. In addition, the logic calculates the remaining expected lifetime. To assess the underlying absolute values it is possible for the maintenance personnel to look at a trend analysis over a given operating time.
4.4. **Output systems** *(Odin, CM on side, …)* for condition monitoring use-cases

Today, Bosch Rexroth service customers have the opportunity to combine the Condition Monitoring System and their installed control and observation system with the cloud-based, predictive analytics service ODiN (Online Diagnostics Network). It combines comprehensive deterministic algorithms with Big Data analytics.

Accordingly, **Figure 7** illustrates the resulting toolbox of vertical networks that ensures a use-case tailored implementation.
5. Conclusion

The authors have discussed i4.0 and the use of i4.0 technologies, using the example of the new ABPAC from Bosch Rexroth. Having elaborated on the understanding and definition of i4.0 and the incorporation of i4.0 and configuration of the ABPAC. The main focus deals with the topic, Condition Monitoring, and how it is advantageously used in the ABPAC. The authors exposed the dilemma in which users concerned with maintenance are able to use predictive maintenance to their advantage. To realize a predictive maintenance concept, it was necessary that the ABPAC use a comprehensive sensor-package in which data is collected from all relevant systems (efficiency level, pressure, filling level, temperature and solid contamination). Additionally, the Condition Monitoring System of ABPAC uses a decentralized sensor node with integrated SPS for the internal analysis and the comparison of the current state with prediction models. This allows for a trend forecast to be generated, which can then be displayed on smart devices or via the Data-Mining-System (ODIN) making predictive maintenance a reality for maintenance personnel. In conclusion, by applying i4.0 technologies, demand-oriented maintenance strategies become economically feasible by providing improved machine availability without extensive additional investments or implementation efforts.

6. References