Condition Monitoring as a Tool to Increase Availability of Multiphase Pumps

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1. Introduction

Parallel to the ongoing process of control hard- and software development, manufacturers of machines and systems started using control systems to monitor the equipment's condition. The target is to increase the machine's up-time and as a consequence the economic viability of the equipment.

After referring to general common methods, I will define condition monitoring as one tool to increase the availability of systems. Then further advantages of this method are considered and the way to successful condition monitoring is described.

The next focus is on the Multiphase- Twin-Screw-Pump- Technology. The fundamental basis for the development of condition monitored Multiphase Pump Systems is the system itself. A common standard is defined and multiple variants of the system and the application are presented. As a vital part of modern Multiphase Pump Systems an IT-platform to generate condition data and common methods of data communication are described.

The main focus of this paper is an outline of existing condition monitoring modules, the benefits of these modules and an outlook on future modules which are part of ongoing research activities.

At last three real case studies are presented, where condition monitoring as a tool to increase system availability has generated its significant advantage.

2. Methods to increase System Availability

In practice there are several methods known and proved to increase system availability.

First of all customers try to choose the product quality with regard to the need of product availability. High-quality products, proven technology and qualified vendors will be preferred if system availability is of capital importance.

To upgrade the system's reliability it is also common practice to use fail-proof and highly reliable components for the vital parts of the system. These components in general use multiple redundant functional units, which are accurately tested on performance. As an example the fail-proof programmable logic control system (PLC) of a pump system should be mentioned.

Another approach to minimize the probability of a system breakdown is to reduce the number of sub-components of a system to a minimum. Every additional sub-component is a potential source of defects and can lead to a malfunction of the system or in the worst case to a system breakdown. An example for a proven integral functional solution in screw-pump systems is the modified motor/pump coupling, which is fitted with fins in order to work like a fan. Without additional components this coupling is able to cool pump bearing and gear housings. No additional fan with motor, which can fail, is needed.

A general influencing variable on the system condition and the duration of system downtime is the technical qualification of the operational and maintenance staff. A well-trained operator knows the characteristic signals of his equipment and will react appropriately, before the system condition will change for the worse. Similarly, a professional maintenance staff member will find the most effective way to repair and restart a plant after a breakdown. As a conclusion investing in the qualification of operators and maintenance staff will have a positive influence of the system's availability.

Of course all routine and preventive maintenance activities also have a direct influence on the availability of machines and systems. Increasing frequency of maintenance activities and intensifying maintenance activities will reduce breakdowns or repair work. Otherwise downtime caused by maintenance work and the relating costs will increase.

At last condition monitoring (abbreviation "CM") should be mentioned as an intelligent method to increase the availability of technical systems. A condition monitoring system in general uses different sensors to monitor on the one hand the condition of vital system components and on the other hand the processes they are used in. An IT-system processes the data and generates the condition data of the system. Contrary to preventive maintenance, where parts and components of a system are inspected and replaced preventively during periodical maintenance activities, condition monitoring should allow condition-dependent maintenance activities. That philosophy of perfection leads to a scenario where the service life of vital components could be utilized at a maximum, based on detailed information about the component condition. According to this maintenance philosophy, a condition monitoring system, together with adjusted maintenance logistic leads to a highly economical operational concept, resulting in low maintenance costs and high system availability.

Beside the increase of system availability condition monitoring in general allows process optimisation, which positively influences the economic efficiency of the equipment. Furthermore, condition monitoring can be a part of a highly effective feedback system.

Operational experience can be gained and used for future product improvement and development.

3. The Way to successful Condition Monitoring

Regarding the factors of success for condition monitoring, the know-how about the vital system components and about the operational process is essential. In general only the combination of component condition data and process data allows evaluating the system condition.

As a concrete example condition monitoring of a wind engine's drive and gear system should be mentioned. After several years of development, including thousands of hours' operational experience, condition monitoring of wind engines today is a proven and effective tool, which is also requested for wind engines by the insurance companies. The combination of evaluated load characteristic of the rotor system and sensor data of the gear system allows making accurate statements about the remaining gear system's service life.

When talking about condition monitoring of multiphase twin-screw pump systems, the same requirements have to be fulfilled. On the one hand an adequate amount of operating hours and field experience in different installations can lead to a deep understanding of the unsteady multiphase transport process. On the other hand basic theory to describe the effective static and dynamic loads and the corresponding load capacity of the vital system components should be known and describable in detail. Without this background condition monitoring of multiphase twin-screw pump systems will not meet the expectations.

To the major properties of a condition monitoring system belong the abilities to collect, to analyse and to store process and condition data at the moment and for previous operating time in order to predict system's future service life.

After the addition of experts' knowledge on a condition monitoring system and the use of collected field experience for maintenance planning and future product improvement and development, the local monitoring system at last needs data exchange to a higher-level control centre. This data exchange can be realized simply by personal data transport or by remote access in different layouts. Security and integrity of the data thereby should have the highest priority.

4. The Multiphase Twin-Screw Pump System

For successful condition monitoring we do not only need the infrastructure (described later on), but also the know-how about the system which has to be monitored and the know-how about the process in which the system works.

When we consider a modern and basic Multiphase Screw-Pump System, the following configuration has to be regarded.

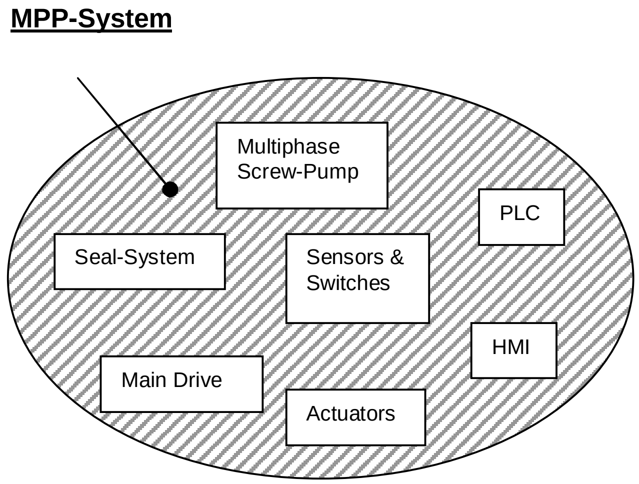

Figure 1: MPP-System

The main component of the MPP-System is the multiphase screw-pump with its seal system and the main drive. The Multiphase Pump- System is controlled by a programmable logic control system (PLC), featured with a human machine interface (HMI). The PLC gets its signals from different sensors and switches (pressure, temperature, vibration, level, speed, power, etc.) and controls different actuators (main drive, valve actuators, actuators of seal system etc.) to keep the MPP-System on-line.

The Multiphase Pump-System is customized to the location, the kind of multiphase medium, the operating conditions and individual customer specifications. All different areas such as desert, permafrost, tropes, offshore top side and even sub-sea are locations where MPP-systems are in use today. The pumps are used to transport heavy crude oil as well as conventional multiphase mixtures of oil, water, parts of solids and natural gas from zero to 98% gas void fraction (GVF). Also wet gas (98% to 100% GVF) and thermal operation at steam-injected fields could be handled. The medium can be corrosive and abrasive; it is explosive and mostly toxic. Multiphase Screw-Pumps are used to reduce wellhead pressure to nearly atmospheric pressure, to increase the discharge of the formation and they are able to boost pipeline pressure, if needed above 100bar. They transport only a few cubic meters of oil per hour from marginal fields or more than 2,000 cubic meters per hour to a central processing unit (transfer pump). Operation happens under permanently unsteady conditions. As a consequence of this wide range of applications Multiphase Screw-Pump Systems have to fulfill a wide range of requirements. Therefore specialized variants of Multiphase Systems are available.

When we take a closer look at the electrical system, the scope of a MPP-System can include a circuit-breaker, a transformer, switchboards, grounding and uninterrupted power supply.
As the main drive an electrical motor and a variable frequency converter (VFD) is a common solution. Diesel or gas engines can be an alternative.
Beside the seal system, that flushes the seals, handles barrier fluid or recovers leakage, other auxiliary systems can be a part of a MPP-system, such as ”compressor units for pneumatic valve actuators, hydraulic systems for hydraulic valve actuators, lube oil circulation systems, cooling systems, fire & gas detection systems, air conditioning, fire-fighting system, fluid injection systems and at last different kinds of control systems”.
Despite of the different boundary conditions like location, process and equipment, a modern Multiphase Screw Pump-System is predestinated to implement a condition monitoring system. The control system as a general part of a Multiphase Pump-System is a perfect basis. In general there is a PLC on skid, which communicates to an HMI via Ethernet and receives all necessary sensor signals. A storage unit for process data is part of most modern Multiphase Screw Pump-systems.
Today a Multiphase Pump-System can be upgraded to perform condition monitoring. The only equipment which has to be added is the intelligent condition monitoring system (industrial PC), its favored modules and a remote access-system (RAS-System) (see figure 2). Retrofitting a modern Multiphase Screw-Pump System should be possible in most cases.

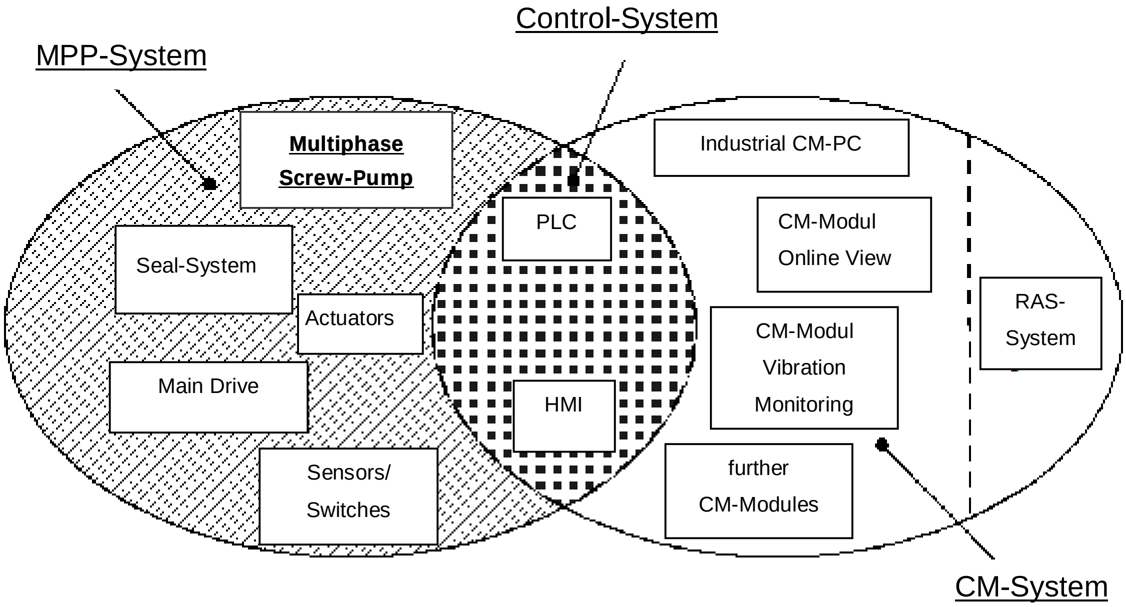

figure 2: Control System of a MPP-Unit and additional CM-Hardware

To connect the MPP-System at all mentioned locations over the world, different proven RAS-Systems are available.

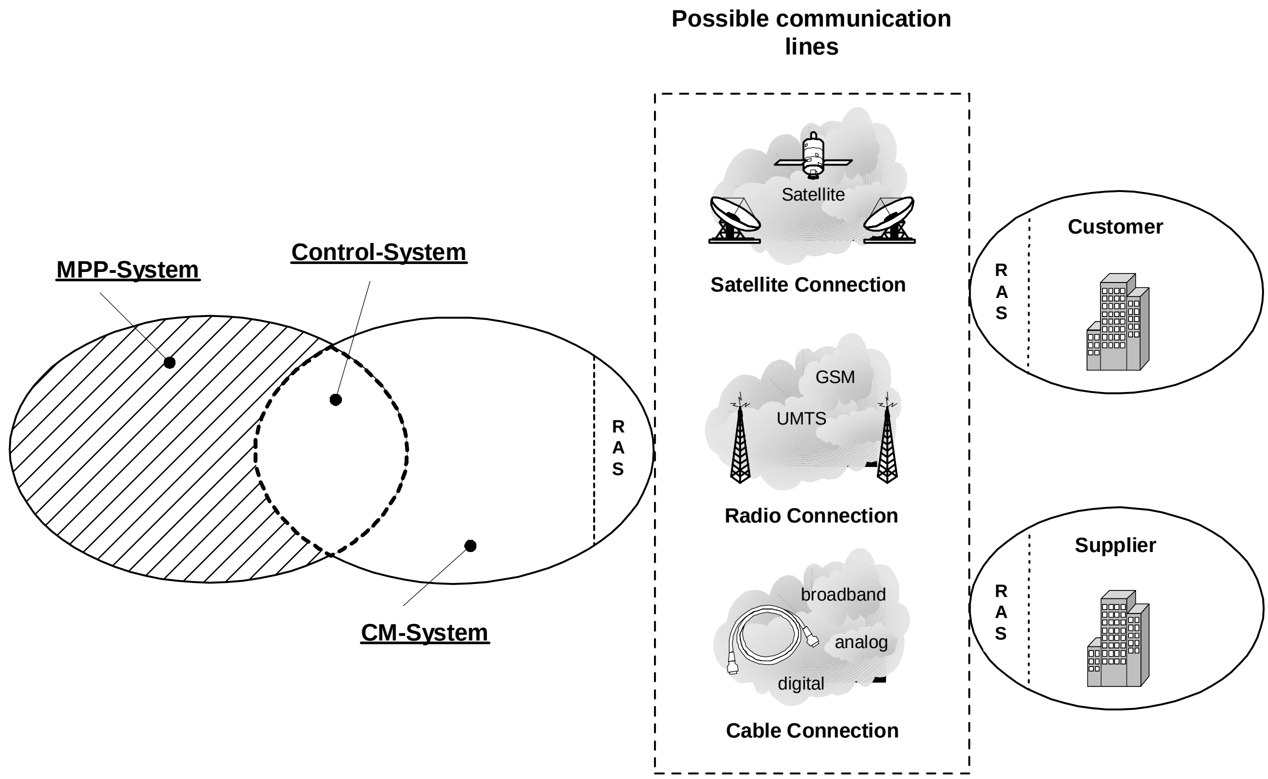

figure 3: RAS-System variance

Driven by the local technical boundary conditions, the MPP-System can be connected via analog or digital telephone line, broadband data communication, GSM/UMTS mobile radio service, directional radio or satellite transmission. These are methods and equipment which can also be used to connect a customer's control room.
Regarding data integrity, data security and hostile network access, the importance and strategic significance of the oil & gas business requires uncompromising solutions. Therefore data communication via a separated world-wide network is favored. This kind of network combines the advantages of internet, like world-wide availability, with the security of a separated network, with known and identified users. At last the operator of a Multiphase Screw-Pump System has to have the sovereign possibility to decide about system access of third parties (full control about the RAS-Hardware contact) and should have transparent insight into data storage procedures.

5. Condition Monitoring – More than pure Maintenance.

The real customer benefit of a condition monitoring system is generated by the available CM-Modules. A basic one is the system online view, which can be realized by remote access to the PLC of the MPP-System. The online view allows every authorized user to have individual access to the process and component condition data. If needed, he can get full access to the control system.

Following the lifetime of an MPP-system, the first significant benefits in use of a CM-System accrue during commissioning and start-up. As a result from the possible online view to the pump-system, different support from third parties during start-up and commissioning can be realized. Experts for the main components such as the pump, control or drive system can be involved during start-up phase on short demand. This access extends the available know-how to a maximum, with minimum costs and maximum flexibility.
Via remote access it is common and proven practice to adjust the system parameter according to the operating conditions needed. Sensor set points, drive parameters, parameters of further sub-systems like cooling systems, lube oil systems or air-conditioning can be influenced to optimize Pump-System operation during the adjustment process within the start-up phase. Also troubleshooting or complete software updates for HMI, PLC or the condition monitoring software itself can be handled via remote access.
Of course online view via remote access by experts is also an effective way to reduce the time for troubleshooting and as a consequence system downtime. Contacting system experts at short notice to have a common view at the system creates additional training effects for the operating crew.
Beside troubleshooting and training support condition monitoring via remote access can also be used to improve performance of the multiphase transport process. Supported by the MPP-System expert operators can adjust pump-systems operation data considering interaction with connected wells upstream or for e.g. a central separator plant downstream.
After we concentrated on the benefits resulting from an online view on the control system, we now consider the CM-Modules. They automatically generate condition data of the vital components of a Multiphase Pump-System.
At first the vital components have to be analyzed and selected. Therefore the central importance of a component with regard to system function and its failure probability has to be considered. As a result of this analysis four main subject areas can be distinguished: the drive system, the multiphase pump, sub- systems in general and operation supplies.
In a drive-system, for example an electric motor, the windings, bearings and the VFD with its sub-control system can be identified as vital components. Looking at the Multiphase Pump, the coupling, conveying elements, bearings, gear wheels and mechanical seals are of major interest. Attention should be paid to all sub- systems. Three years of observed operating time of a Multiphase Screw Pump System within the MPA-Research Project from 2003 to 2006 [1] have identified malfunction of sub-systems as a relevant factor. The operation of hydraulic pumps, compressors or valve operating mechanisms has to be taken into consideration. At last the operation supplies of a Multiphase Pump System such as lube oil, pump’s liquid

filling, barrier fluid or flushing of mechanical seals, batteries of uninterrupted power supplies or contamination of filter cartridges have a bearing on the system's service life and possible system breakdown.

When we look at the drive system in detail, the condition of windings can be monitored by winding temperature (adjusted by local ambient temperature) in relation to the requested hydraulic power of the pump (depending on speed and differential pressure). The condition of the motor and also of pump bearings is monitored by bearing temperature, in relation to speed, pump's differential pressure, medium temperature and the local ambient temperature. Of course vibration control is an effective tool to notice occurring bearing failures. Depending on the brand of frequency converter, its internal control system generates condition data, which can be transmitted to the main control unit of the MPP-System.

To calculate the condition data of the screw pump's vital components, the vibration analysis is the effective CM-tool. In relation to characteristic process data, like engine power, speed, differential pressure, pressure ratio or component and medium temperature, vibration monitoring is able to analyse coupling misalignment, failures of the outer and inner ring of bearings or damage of roller elements, beginning damage of gear wheels, conveyor screws or shafts. The condition of mechanical seals can be analysed by monitoring leakage rate in relation to seal differential pressure, temperature and speed. Not cost-effective for every application are shaft seals with integrated condition monitoring sensor [2]. An optical sensor detects leaking liquid (oil or water) on the surface of a special fabric and informs about occurring seal failure before it comes to the worst.

Regarding common MPP sub-systems such as hydraulic systems for double acting mechanical seals, hydraulically driven valves or compressors for pneumatic actuators, abnormal operating time of actuators in relation to characteristic process data like engine power, pump speed, differential pressure or pressure ratio of Multiphase Pump, process medium temperature, component temperatures or vibration level of the system can give preventive information about occurring malfunction of sub-systems.

Control of operation supplies can mainly be exercised by recording the tank levels and analysing the oil consumption during a defined time span. The battery charging condition can be analysed continuously and contamination of filter cartridges in general is monitored by a differential pressure transmitter.

A part of ongoing research activities is the theoretical calculation of the remaining component service life. The focal points-of- interest are the conveyor elements, the bearings and the mechanical seals of the multiphase pump. Especially for mechanical seals, a German manufacturer is working on a CM-Module to calculate the seals' remaining service life, with first positive results for applications with pure water [3].

6. Practical Examples - fast and cost- effective solution with condition monitoring

Below three practical examples for successful usage of condition monitoring and remote access to pump systems operating in the oil and gas industry are described.

The first example is troubleshooting at a multiphase pump-system on a North-Sea platform. The operator informs the pump-system experts via telephone that it is not possible to close the air-inlet shutter of the system. As a consequence operation is limited.

After receiving an individual and temporary password, the system experts contacted the MPP-system's control system via remote access. A private security network from the experts to the on-shore basis is used as communication line. From the on-shore basis to a central processing platform the signals were transferred by submarine cable. From the processing platform to the satellite platform with the MPP-System a radio link system was used. Together the MPP-System expert and the software specialist accurately checked the PLC and HMI signals to the inlet shutter. No failure could be identified. To check the mechanical function of the fail-safe closed inlet shutter the expert cut off the electrical power by remote access and the operator at site could see the inlet shutter moving correctly in the close position. This test reduced the possible reasons for the malfunction to a failure of the inlet-shutter drive (nearly unrealistic as a protected electrical motor is used) and to the control relay of the drive. A visual inspection of the relay indicated heavy wear at the relay, which caused malfunction. After identifying the type of relay, it was ordered, sent to the platform and was substituted by the platform electrician. Altogether four to five hours' work for one operator on-site, the pump system expert and the software specialist were necessary to analyse and solve the whole problem. In contrast to this remote access supported solution, the conventional process of a field service trip, which is usually performed by a software expert and the technician for the MPP-system, takes four to six days, depending on the flight schedule. Estimated costs would differ by factor ten.

In my second practical example online view via remote access is also used to get a fast solution of a quite common problem. After some months of MPP-System operation the process parameters had changed and medium temperature in pump casing and in discharge piping had increased to an unexpectedly high level. The fixed set points for the temperatures had been exceeded several times and continuous operation had not been possible any longer. After technical clarification of the pump system's design limits and detailed check of the changed process data via condition monitoring, the manufacturer of pump system and operator decided to adjust the temperature set points via remote access.

Similar to the first example the operator enabled the external experts to enter the system by remote access as he connected the hard-wired communication line on-site and the expert logged in via an individual password. These two steps of the login procedure guarantees the operator full control of access. Due to safety issues, MPP-system operation had to be stopped, before logging in via remote access in order to modify the PLC-software code. The new maximum set point had been adjusted and the alarm set point had been modified too, on the human machine interface (HMI), by using a special password level. Three hours later the system could be restarted again and operation could be continued without further interruption caused by a high-temperature shut-down. No software specialist had been at site, no flight had been taken.

The third praxis example describes the use of a condition monitoring system incorporating vibration monitoring. It is in use at several high pressure crude oil pumps, driven by a diesel engine. The system is fully equipped with suction and discharge pressure sensors, temperature sensors, speed sensors, displacement sensors for crank shaft and vibration monitoring systems. Vibration sensors are positioned at the motor and at the pump. Additionally all sensor data can be compared and correlated. Frequent analyses of the pump system's dynamic characteristic are automatically made, including important components like bearings, coupling and gear wheels. The vibration monitoring system is combined with the other process data. Frequent protocols from a team of experienced pump and vibration monitoring experts are possible. In these protocols the condition of the monitored component is mentioned, beginning at the start-up of the system, where a fingerprint of the dynamic characteristic has been taken. Critical developments are directly transmitted to the system's control panel. One part of the permanent analysis is the check of bearing frequencies. By this, a potential breakdown of bearings can be predicted. Adjusted maintenance activities prevent avoidable costs and downtime.

References

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[2] Freudenberg Simrit GmbH Co. KG; 17.04.07 technical information “Shaft seals with bidirectional Condition-Monitoring”.

[3] Product news EagleBurgmann Wolfratshausen / Germany.