

Predictive maintenance –
the strategy that predicts
when machinery will require
maintenance



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“Damage can always be prevented if appropriate steps are taken in due time.” There’s no better way of describing the main benefit of predictive maintenance.

The principle is based on three pillars:

1. Permanently monitoring the condition of a “healthy” system to detect wear or variations from the normal condition early on – fluid condition monitoring
2. If a variation is detected, in the simplest case only an alert is issued, but a better option is to determine and output the remaining service life of a component or a subsystem – as per Industry 4.0
3. On the basis of this “condition” of the system, costly downtime can now be reliably avoided and inexpensive maintenance can be scheduled.

This type of “condition-based” strategy creates the conditions for enabling negative changes in hydraulic and lubrication systems to be detected early on and countermeasures to be initiated in due time. Virtually every fluid system comes with a multitude of ways to consistently monitor the condition of the fluid and save on unnecessary costs.

In hydraulic and lubrication systems, friction, wear, leaks and excess temperatures can contribute to the operating fluid becoming contaminated, with solid particle contamination or water, for example. This contamination then goes on to cause errors in components and subsystems and ultimately in the system as a whole. Furthermore, the normal ageing process of the fluid causes performance losses that often result in system downtime. In order to prevent these time-consuming and costly consequences, monitoring the condition of the operating fluid is of major significance. The condition of the operating fluid is comparable to a “fingerprint” of the overall condition of the system. Systems for permanently monitoring fluids (online fluid condition monitoring) in this

context become a crucial system component. They support both machine owners and manufacturers in their efforts to increase machine availability, perform only scheduled maintenance when possible, and ultimately reduce the overall cost of the machines over their working life. For numerous production plants and in fleet management, the cost-based decision-making criteria for new investments is no longer just the procurement cost of a machine. What is also evaluated is what is referred to as the life cycle cost (LCC), or the cost over the machine’s entire service life. In addition to procurement costs, this LCC also includes the costs for operation and disposal. This ultimately reduces the actual overall cost per unit in order to stay competitive in the global market. Add to this certain customer requirements that have changed over time.

Current customer requirements, using the example of mobile mining equipment:

- Higher productivity
- Greater breakout forces
- Higher efficiency

To meet these demands, the industry increasingly relies on the use of the following (in addition to other measures):

- Electro-hydraulics
- Higher system pressures
- Tighter tolerances
(now in the single and double-digit μ -range)

An inevitable side-effect of this trend is the fact that machines are becoming increasingly sensitive to contamination in the oil. If the cleanliness level is not monitored and efforts for improvement not made early enough, wear and tear can gradually reduce the system efficiency. Sometimes the system efficiency can fall by 20% before the machine operator even notices a problem.

Fluid Condition Monitoring at a glance:

- Continuous monitoring of the machinery via the condition of the fluid and the fluid conditioning components
- Integral part of a predictive maintenance plan
- Maintenance intervals can be planned according to need
- Helps to reveal defects and developing damage in due time
- Helps to prevent unplanned machine stoppages
- Increases availability, safety and productivity
- Increases efficiency, because components no longer have to be over-sized
- As part of the Life Cycle Management, costs can be saved

This can be prevented by using efficient Fluid Condition Monitoring (FCM) sensors and subsystems. These detect the deviations at an early stage and enable the user to take predictive corrective action in good time.

Market requirements

The current market requirements for production machines are shown in Fig. 1.

These apply generally to both stationary and mobile machines. Two basic requirements are:

- Immediate alarm in the event of serious errors
- Reduction in the unit costs of a product (where “product” can refer to a machine-produced part or a hauled tonnage per hour)

In order to meet these requirements, the machines must always have the characteristics in Fig. 1.


Customer specification	Fluid condition sensor
Alarm for (fatal) errors	Monitoring of the <ul style="list-style-type: none"> ● planned fluid operation properties (temperature, purity, etc.) ● installed fluid conditioning components (cooler, filter, etc.)
Reduced unit costs 	Reduced life cycle cost <ul style="list-style-type: none"> ● Procurement costs ● Operating costs ● Disposal costs
	Increases in <ul style="list-style-type: none"> ● Availability ● Reliability ● Efficiency & productivity
	Full utilisation of the service life of critical machine parts

Fig. 1 Current market requirements for production machines

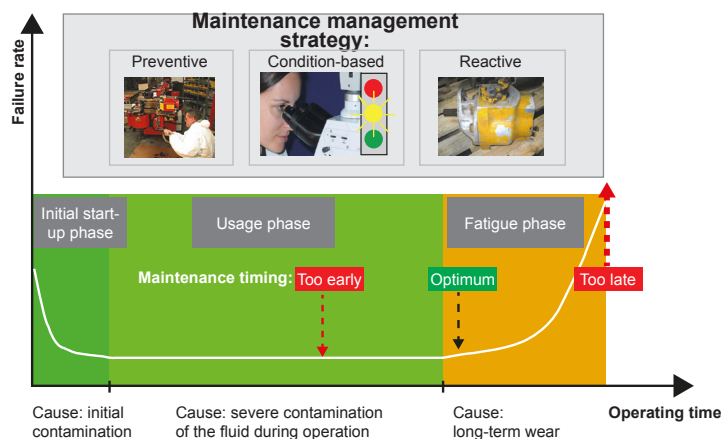


Fig. 2 Typical service-life curve of a fluid system

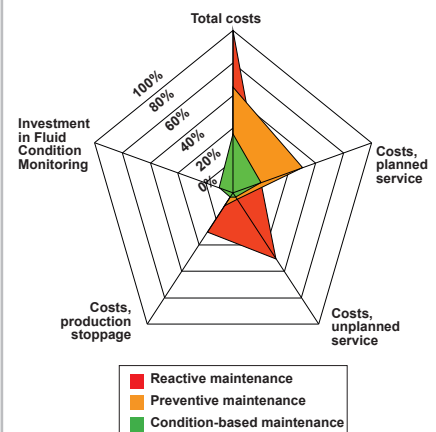


Fig. 3 Typical maintenance cost distribution of the three systems

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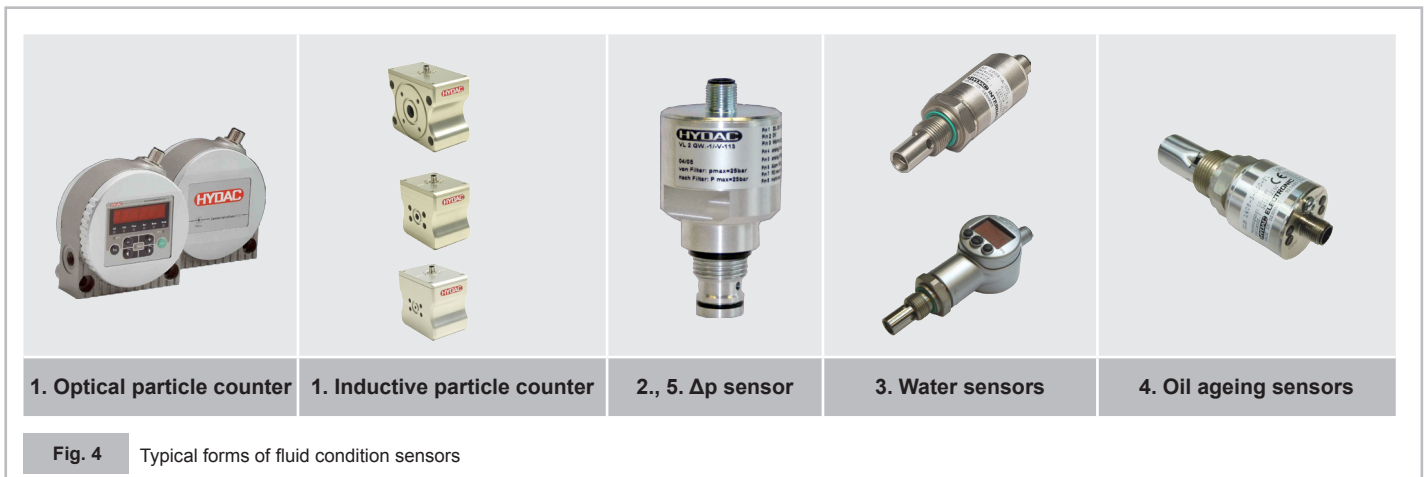
Condition-based, predictive maintenance strategy

In order to meet the above-mentioned demands, an appropriate maintenance management concept must be established. “Reactive” strategies (operation until failure) and “preventive” strategies are unable to minimise the total costs for downtime, maintenance and component exchange (see Fig. 3, page 3). The choice must be for a “predictive” concept, which is the only one that allows the service life of all critical machine parts to be fully utilised, by detecting a “rise” in levels (“optimum” in Fig. 2, page 3) which indicates the start of a (fluid) deviation from the normal condition. This is the basis of a substantial reduction in operating costs by cutting out or minimising expensive and unplanned maintenance and stoppages. As soon as the beginnings of a variation are detected, it is possible to estimate how much service life remains for the corresponding parameter or component and to use this service life in a controlled manner for ongoing production. Meanwhile, spare parts can be procured and maintenance with minimal costs can be scheduled.

To clarify this point further, the advantages and disadvantages of different maintenance management concepts can be differentiated as follows:

- In the reactive model, the biggest cost factors are unplanned maintenance and production stoppage.
- In the preventive model the biggest cost factor is the high proportion of planned maintenance. Moreover, components are rejected which could continue to be used.
- In the predictive model, there are some small additional costs initially for the Fluid Condition Monitoring System, but the total operating costs and therefore the LCC are the lowest.

The typical cost distributions of the three maintenance management strategies are compared in Figure 3. A suitable Fluid Condition Monitoring (FCM) System always forms the basis of predictive maintenance management. In practice, two types of FCM can be implemented, as shown in Table 1:





	Periodic / offline	Continuous / online
Implementation	Service crew with portable equipment	Integration of sensors
Features	<ul style="list-style-type: none"> • Oil sampling, measurements using particle counters • Monitoring the measurements over longer time periods • Variations result in specific measures 	<ul style="list-style-type: none"> • Permanent sensor installation • Definition of limits/alarm thresholds • Remote data transmission to monitoring centres or control rooms via intranet/Internet/GSM/satellite • Variations result in immediate specific service measures
Examples		

Table 1 Forms of Fluid Condition Monitoring (FCM)

Increase in efficiency

A further cost advantage of Fluid Condition Monitoring is obtained right from the design stage because of the possibility of improving the sizing of the components:

- Components no longer need to be over-sized and therefore more expensive.
- The risk of components being operated at the limit is eliminated.
- The system has a higher efficiency as a result.

Online fluid condition sensors

The greatest benefit of permanently installed fluid condition sensors and subsystems is the facility to monitor the fluid condition

- on a continuous basis
- practically in real-time.

The key system characteristics to be monitored and the appropriate sensors (to complement the conventional sensors for pressure, temperature, flow rate etc.) are listed in order of priority in Table 2.

For implementation in a predictive maintenance concept, the electrical sensor outputs must be configured according to the following guidelines:

- Essentially, the output signals must enable the system or the operator to estimate the remaining service life of a component or a process to carry out planned maintenance.
- Switch outputs alone are usually adequate for slow processes.
- Analogue or digital bus outputs should ideally be used for highly transient processes.

System characteristic	Fluid condition sensor
Wear	1. Solid particle sensor
Fluid cross-contamination after addition of incorrect fluid or leakage	2. Differential pressure sensor for filters
Water ingress through condensation or leakage	3. Sensor for free or dissolved water
Fluid ageing condition on basis of hydrolysis or oxidation	4. AN (acid number) sensor 5. Differential pressure sensor for filters

Table 2 Typical applications for fluid condition sensors



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Predictive maintenance in practice

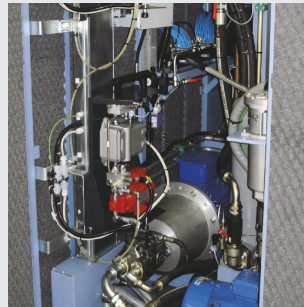
The following practical examples show ways that Fluid Condition Monitoring can be used to reduce costs:



Aviation – hydraulic aircraft pumps

In aviation the guaranteed service life for hydraulic pumps is normally 10 years. This leads to intensive quality tests and as a result, higher warranty costs over the whole life cycle of the pumps.

Task	To reduce both the costs of inspection (previously carried out manually, with individual oil sampling and analysis) and the warranty costs.
Solution	The number of wear particles produced during the function test is a measure of the service life of every pump. Therefore online particle sensors were tried out on the test rigs and introduced as online quality testing.
Result	Inspection and warranty costs reduced by >10%.



Mobile industry – mining vehicle fleets

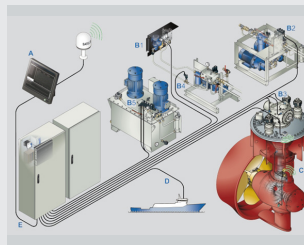
In the mining industry availability and efficiency are paramount.

Task	Reduce unscheduled maintenance, extend the service life of critical components and oils, increase availability and efficiency.
Solution	Use of portable particle counters and offline filtration, both periodically and when limit values are exceeded. Depending on the local circumstances, sample bottles, portable particle counters and online sensors are used to detect excessively high contamination levels.
Result	Unplanned maintenance work was reduced, availability and component service life was increased (availability +10%, reliability +35%, unplanned repairs -35%)



Marine/offshore industry

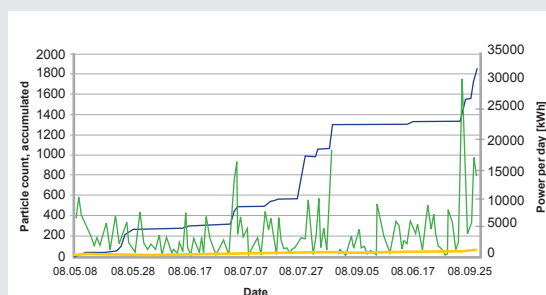
Task	Monitoring of the required oil cleanliness for wear prevention and water ingress into the lubricating oil of thruster drives via seals
Solution	Installation of online fluid sensors in the form of a ready-for-connection, application-specific all-in-one solution
Result	<ul style="list-style-type: none"> ● Required thruster availability secured ● Dry dock waiting times reduced by >60%





Wind energy – wind turbine gearbox

Task	To monitor the gearbox lubrication system online in order to prevent secondary damage and also production stoppages (electricity generation).
Solution	Installation of a Metallic Contamination Sensor (MCS) for full-flow monitoring of the lubrication circuit.
Result	<ul style="list-style-type: none"> As the image shows, a Metallic Contamination Sensor (MCS) was used to detect a bearing failure. The curve shows the number of accumulated particles, i.e. the amount of metal detached from the driving gear. Each jump corresponds to one or more detected metal particles. The first warning was confirmed by a visual inspection because the main bearing showed slight damage but this was classed as non-critical. Consistent with this, a repair was planned and until then the wind turbine could continue to be operated at 80% capacity (the lower curve in the graph shows the power generated). The progress of the damage was monitored until the bearing repair was performed. No unplanned maintenance or downtime was required and the costs for a new gearbox (roughly €360,000) could be avoided.



Steel industry – rolling mills



In rolling mills the operating fluid for controlling the rolls is exposed to very high rates of solid-particle and water ingress. This is inherent to the conditions of hot/cold rolling processes.

Task	To reduce unplanned maintenance and downtime costs by installing fluid sensors.																		
Solution	Standardisation of a Fluid Condition Monitoring subsystem and its integration in the hydraulic circuit. The subsystem consists of a visual particle sensor, a water sensor and a data-logging device with display.																		
Result	<p>The maintenance and downtime costs could be significantly reduced.</p> <div style="display: flex; align-items: center;"> <div style="flex: 1;"> <p>Roll adjustment in steel works</p> <p>Legend: ■ Before (no FCM), ■ After (with FCM)</p> <table border="1"> <thead> <tr> <th>Category</th> <th>Before (no FCM)</th> <th>After (with FCM)</th> </tr> </thead> <tbody> <tr> <td>Total costs</td> <td>100%</td> <td>62%</td> </tr> <tr> <td>Planned maintenance</td> <td>20%</td> <td>20%</td> </tr> <tr> <td>Unplanned maintenance</td> <td>30%</td> <td>10%</td> </tr> <tr> <td>Production stoppage</td> <td>50%</td> <td>30%</td> </tr> <tr> <td>FCM</td> <td>0%</td> <td>2%</td> </tr> </tbody> </table> </div> <div style="flex: 1;"> </div> </div>	Category	Before (no FCM)	After (with FCM)	Total costs	100%	62%	Planned maintenance	20%	20%	Unplanned maintenance	30%	10%	Production stoppage	50%	30%	FCM	0%	2%
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Conclusion

The examples listed clearly show that using Fluid Condition Monitoring in combination with a predictive condition-based maintenance system and appropriate measures can help to considerably reduce the maintenance and the corresponding life cycle cost of production machines.

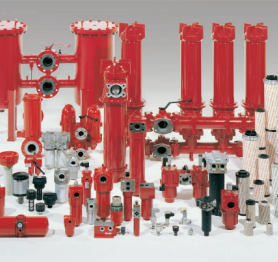
Further additional benefits are:

- Rapid notification when fatal errors occur
- Opportunities for optimising component and system service life

Fluid Condition Monitoring is therefore an efficient system design element for reducing the life cycle cost of modern production machines, predestined for the design of predictive maintenance strategies.



Accumulators 30.000



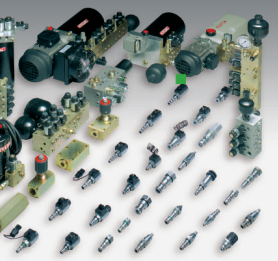
Fluid Filters 70.000



Process Technology 77.000



Filter Systems 79.000



Compact Hydraulics 53.000



Accessories 61.000

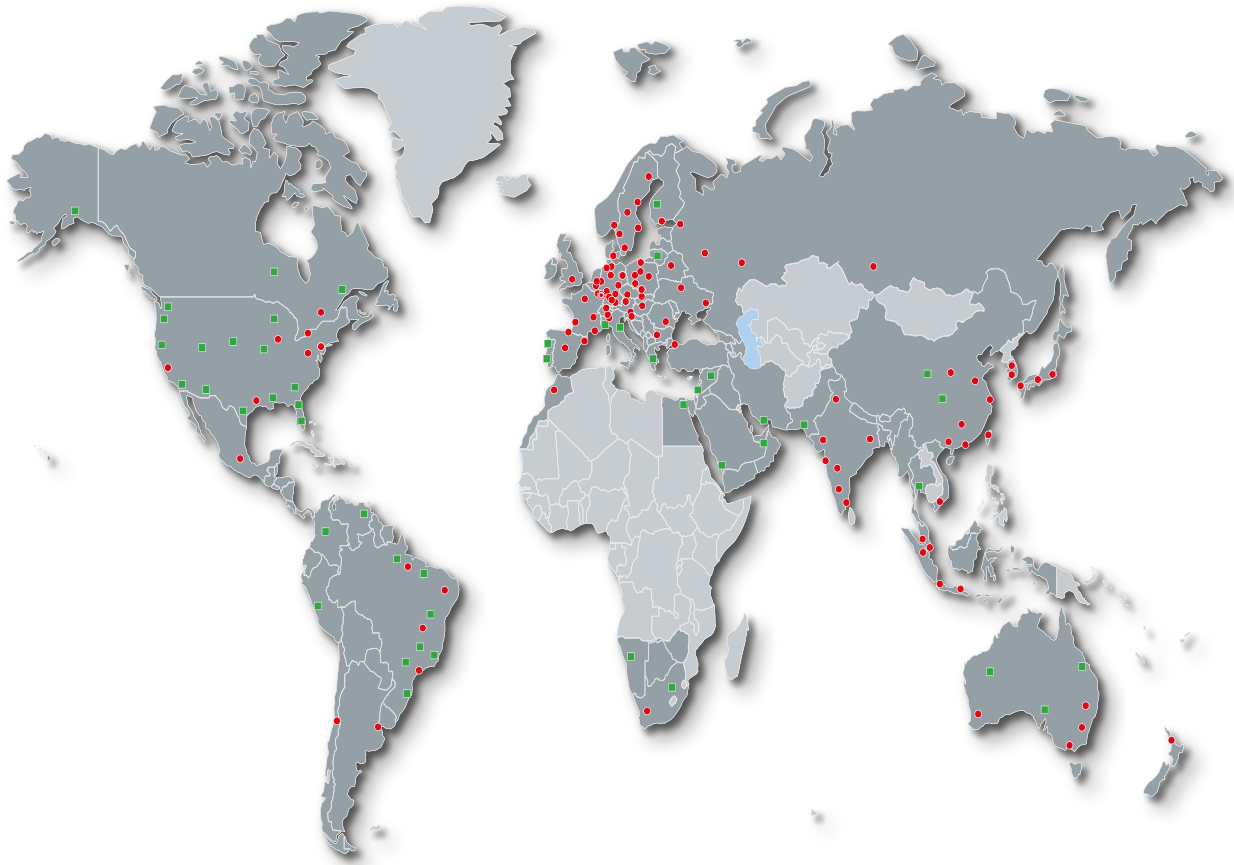





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