JAQUET TECHNOLOGY GROUP

MDS 4500, Diagnostic system for diesel engines| 2014

In charge of speed and more…

JAQUET TECHNOLOGY GROUP
125 Years | 1889 – 2014

The JAQUET Technology Group
General Presentation

The concept of the MDS4500
Technical background, general possibilities

Experience's with the MDS4500
How to save money and prevent major damage

The product Roadmap
One idea, many products – adapted to the specific needs

Condition monitoring

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In the times when well oiled and furbished mechanic, coal, fire, smoke and steam represented the world of machines…

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…condition monitoring was mainly a manual job.

Attention, diligence and a many years of experience characterised the men at the wheel…

They lived for and with their machines and felt every change long before severe damages could happen.

Condition monitoring

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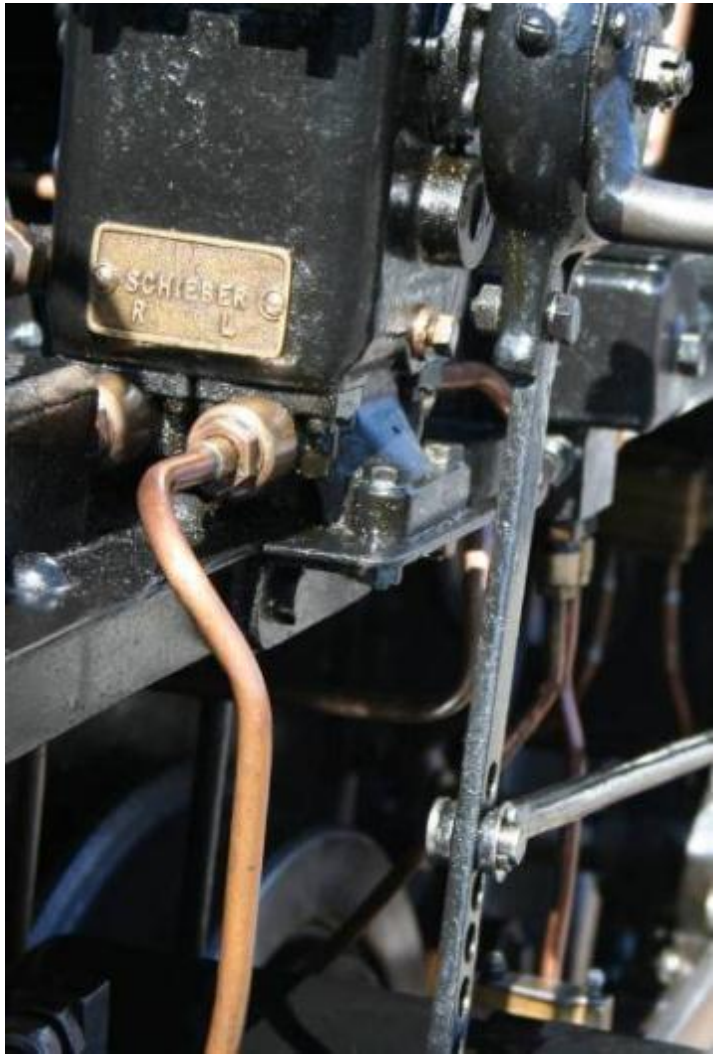
Today, where everything must be a little faster...

Condition monitoring



Today, where everything must be a little faster...

…and things tend to get even more complex than in the old days…

Condition monitoring

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…the need for easy to handle but reliable and accurate tools that can overlook and monitor the many different events that can happen in an engine…

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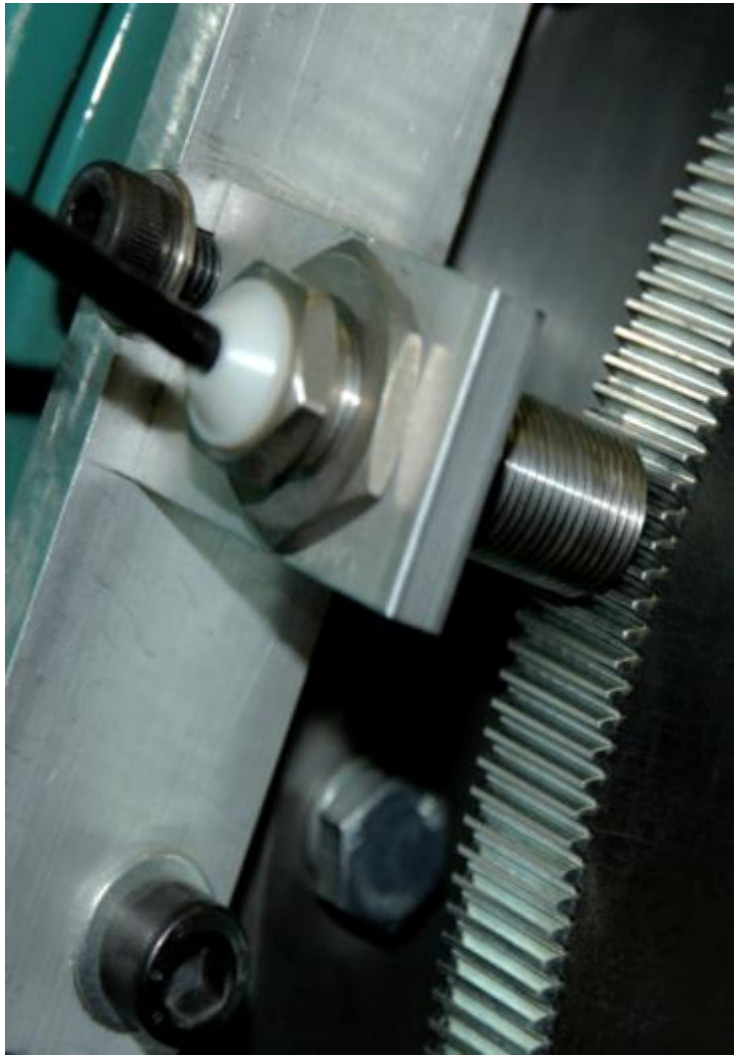
…the need for easy to handle but reliable and accurate tools that can overlook and monitor the many different events that can happen in an engine…

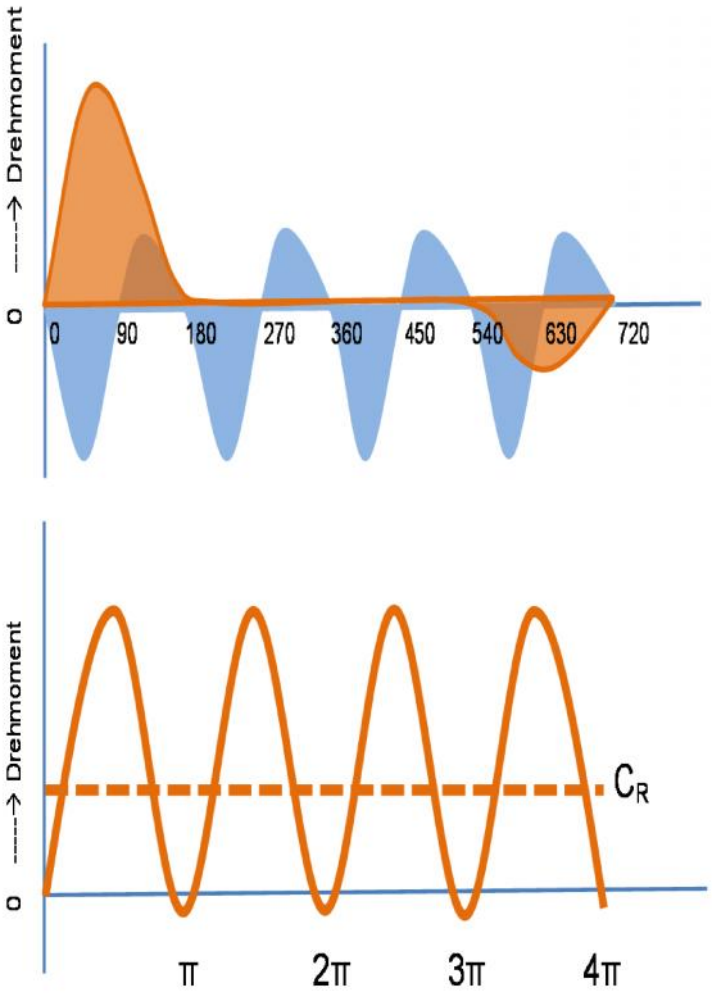
…and deliver this information to the right people just in the time needed for decisions regarding maintenance and availability.

Technical concept of the engine diagnostics



- The engine speed of a Diesel engine is not a constant figure. Linear accelerations, compression and combustion are influencing the instantaneous speed.
- Like in a tone of an instrument these variations can be found in the form of harmonics as a complex transformation of the base frequency – the speed itself.
- In that sense the speed signal – created from the number of teeth and the time for one full cycle of the engine – provides a carrier of the desired information.
- The appearance or disappearance of certain harmonics and their phasing, relative to the dynamic position of the engine, are the raw material of the diagnostic.

Technical Background



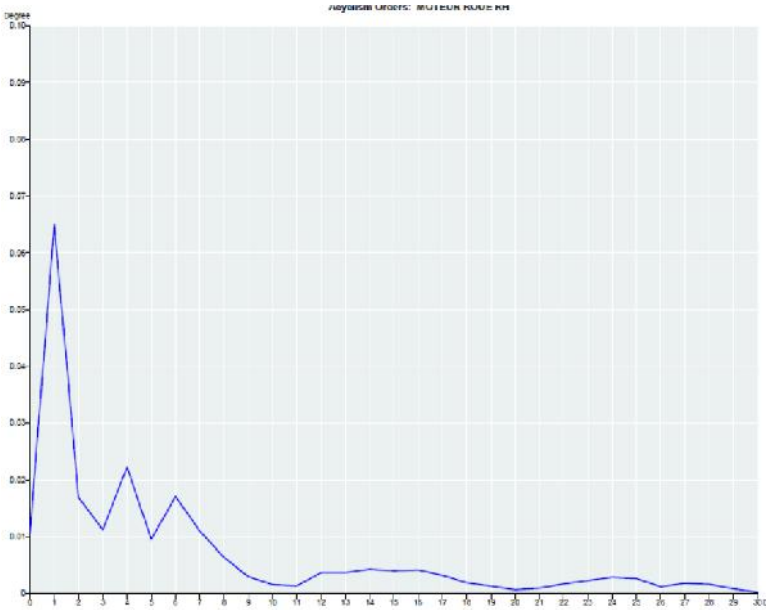
For each cylinder the resultant torque is composed out of the inertia of the masses in movement (blue) and the gas-torque (brown).

Over a full cycle of 720° each cylinder will contribute with that pattern to the total delivered torque to the whole engine.

For a 4-stoke engine with 4 cylinders the instantaneous torque over the full cycle follows the shown curve with a resultant torque equal to the dotted line.

It is showing a torque peak for each cylinder at the time π/2 (90°) and a minimum of delivered torque at π. Often flywheels or dampers are used to smoothen these peaks.

Technical Background



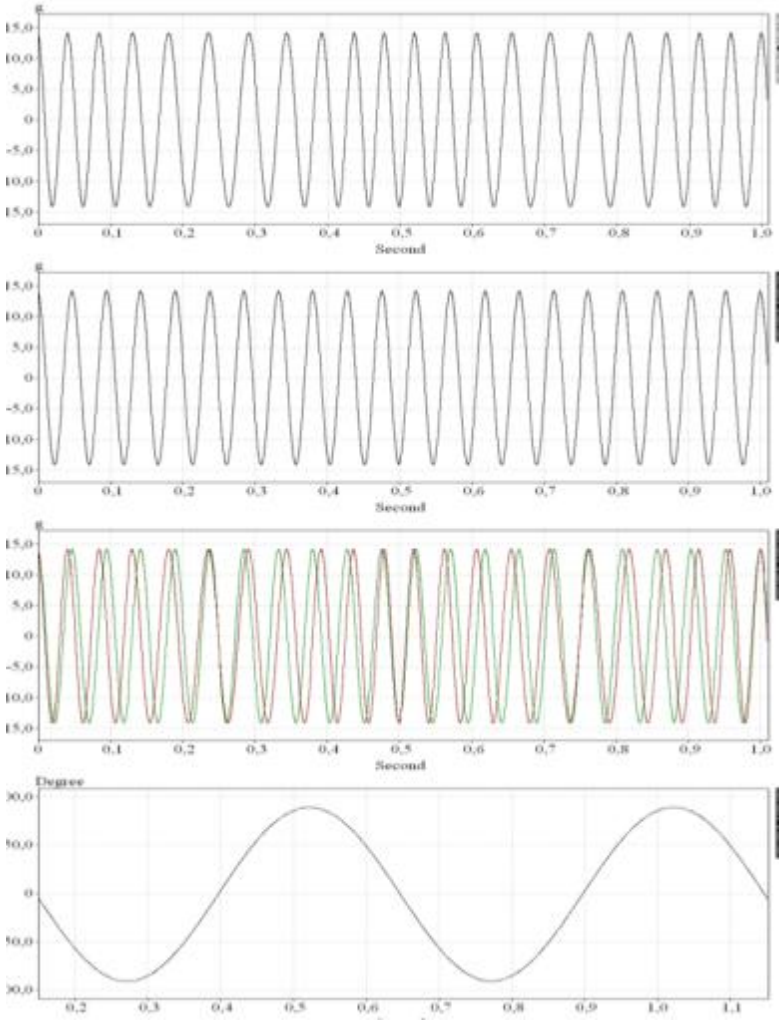
Each engine has, based on its design, a major harmonic. For an in-line 4 cylinder with a firing order of 1-3-4-2 this major harmonic has the order 2 (2nd Harmonic).

The torque components delivered from harmonic orders 0.5, 1 and 1.5 are under normal condition internally compensated, whilst the 2nd harmonic of each cylinder add to each other.

Engine design seeks to smoothen peaks by eliminating this cumulation, by variation of the V-angle, the firing order or counter weights on the crank shaft.

The distribution of the harmonics and their phasing relevant to the dynamic position as well as the appearance or disappearance of expected harmonics are the major basis for the diagnostic information.

Technical Background



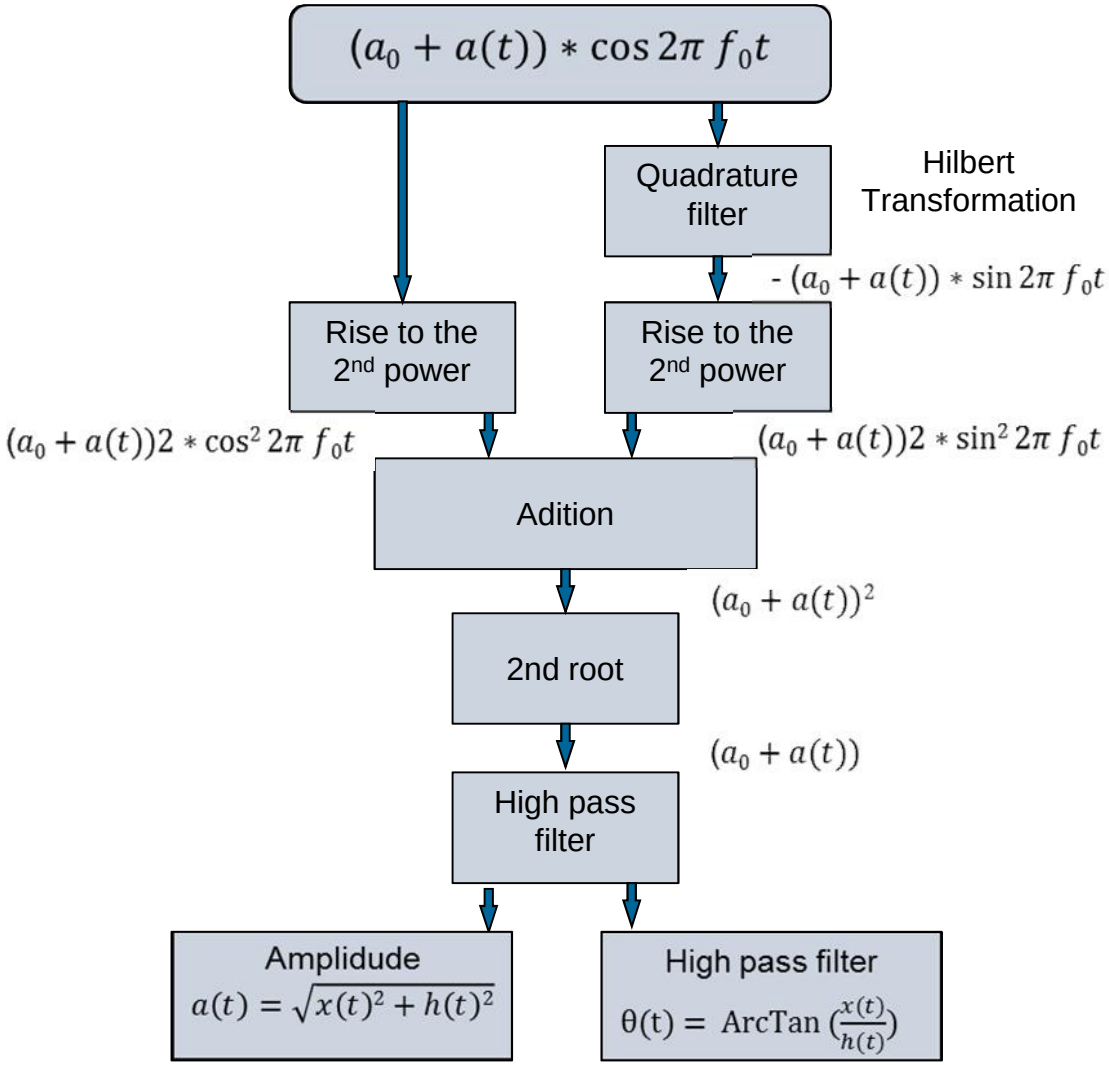
Trace of the measured speed over one full cycle of the engine.

Composition of the ideal frequency as a results from the time of one full cycle (720° for a 4-stroke engine) and the number of teeth of the target.

The diagnostic information is contained in the difference between the two waves: The real measured frequency and the ideal sinus from the same period.

All further calculations are based on this calculated difference.

Technical Background

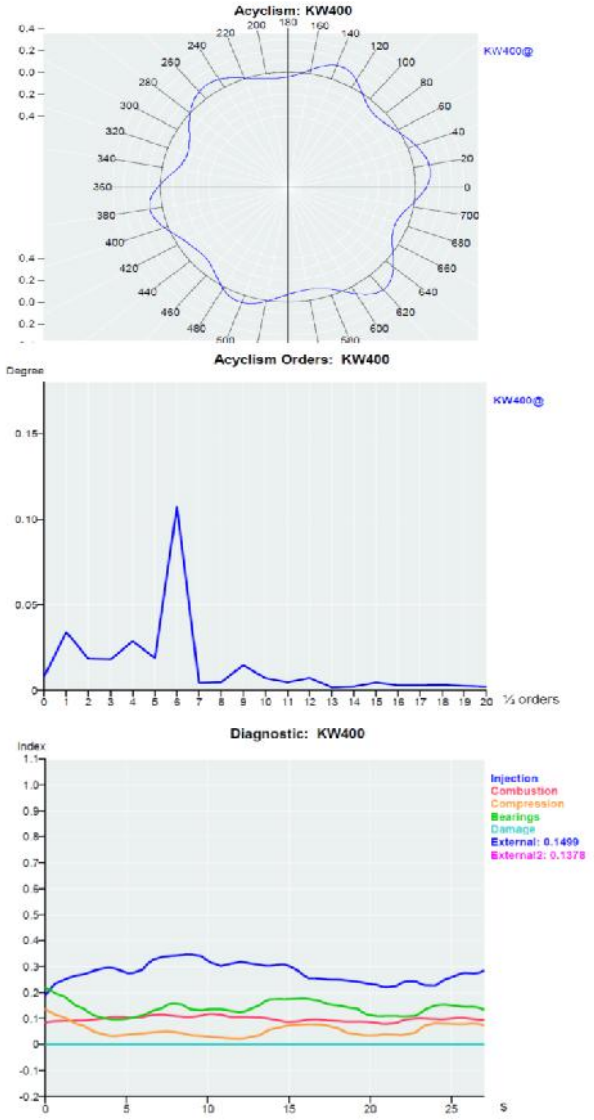


The relevant information for the diagnostic is the difference between the measured signal and the pure sinusoidal wave of the same frequency over one full cycle of the engine.

With mathematical functions this difference signal is calculated and used as the base for the diagnostic information.

The formula is solved for both the amplitude and the phase of the resultant difference signal.

Technical Background



Cycle by cycle the software calculates the distribution of the harmonics and the contribution of the cylinders.

The diagnostic results are expressed by 5 calculated indicators. These indicators have a normalized value between 0 (OK) and 1 (not OK). Also the magnitude of variation over the measured time is considered.

Indicator	Description
Injection	Shows the distribution of pressure during the combustion phase of the cylinders.
Combustion	Gives an indication of abnormal fuel consumption. It represents the real symmetry between compression / relaxation phases.
Compression	It shows the regularity of the compression in all cylinders.
Bearings	It is the image of the dynamic behavior of the crankshaft bearings.
Damage	Identifies the presence of irregularities (pulses) generated by mechanical damage.

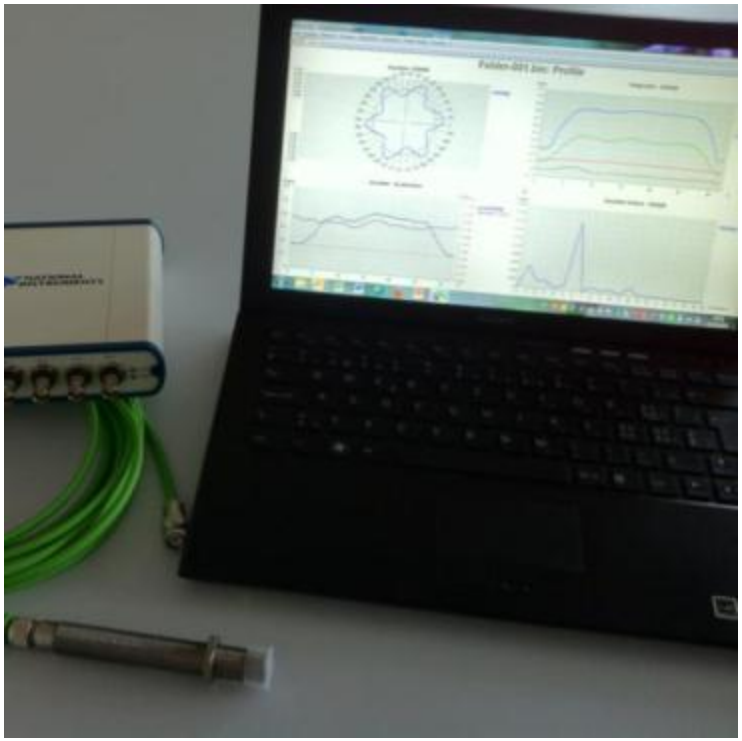
Requirements for the use of MDS 4500

- Only a few things about the engine needs to be known:
  - Number of cylinders
  - Mechanical concept (in-line or V-type / 4-stroke / 2-stroke)
  - Number of teeth of the crank-shaft pole wheel
  - Concept of distribution of the results
- An accessible pole wheel / target as close to the crankshaft as possible (minimum number of teeth is 60) and measure this wheel with a JAQUET speed sensor.
- Should an indication by cylinder be required, an index sensor to synchronise the system and indicating the TDC of the first cylinder must be applied (for example at the cam-shaft gear).
- It is possible to process more than one speed signal in one system. This can be used
  - to eliminate torsion influences with long crank shafts
  - to analyse auxiliary systems such as the Turbocharger
  - to measure the static / dynamic torque value of a system
  - to measure 2 engines with 1 MDS4500 (i.e. portside/starboard)

The product concepts

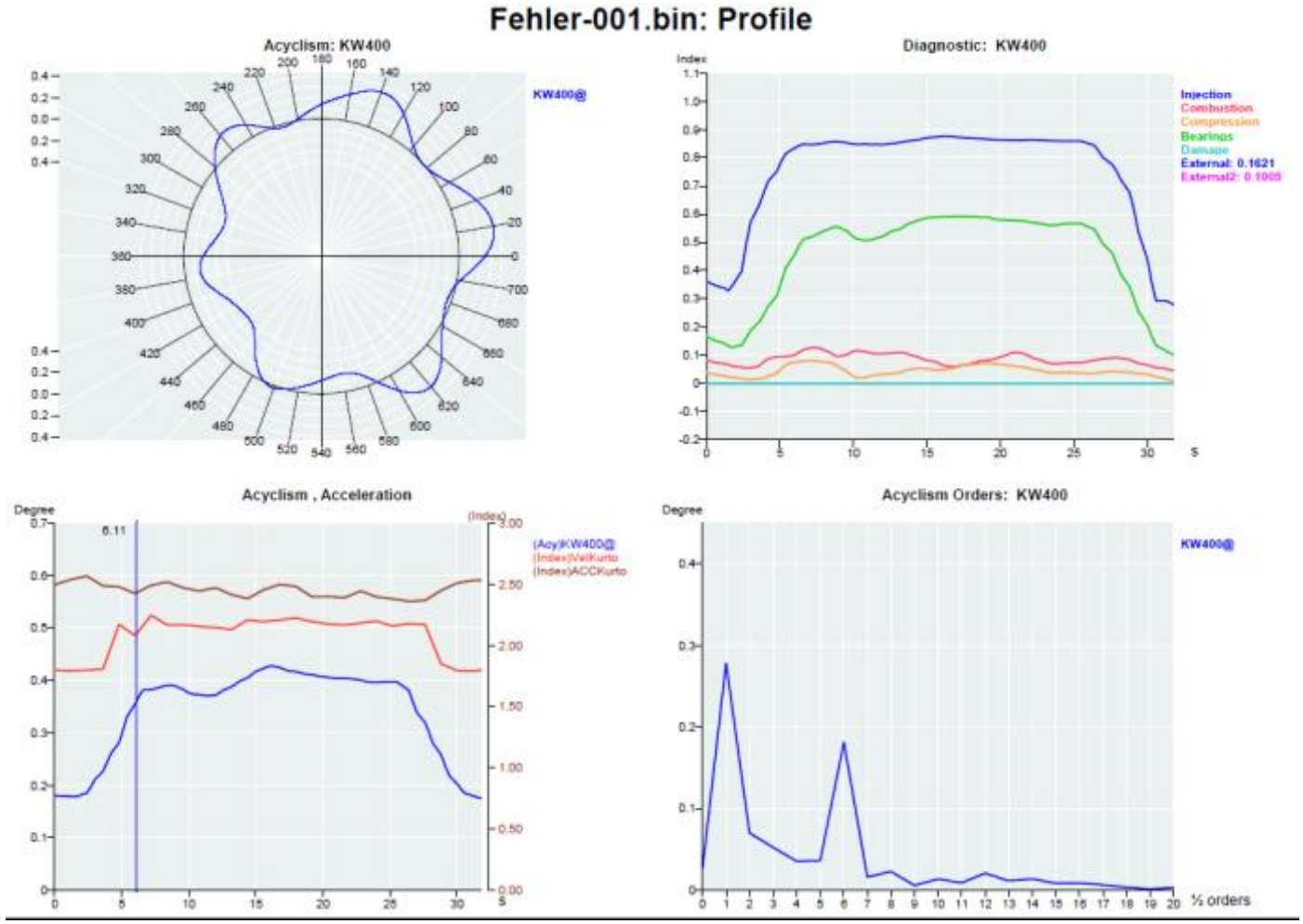
- **The «System for the Experts»**
  The PC-Windows based software VIB360 allows an expert to deeply analyze engines, rotating equipment like turbines, compressors, windmills and gear-boxes. The delivered results can be used to establish precise and well-founded reports for the users and owners of the equipment in question.

The System for the Experts



- The program VIB 360 is installed on a standard PC. Captured data from various rotating machines can be analysed in depth and the graphs and figures can be used to establish relevant reports for the users/owners of the machines in question.
- The program can be used for all kinds of rotating equipment: From 2- to 4-stroke engines to turbines reciprocating compressors, wind-mills of transmission elements and gear-boxes.
- The “Expert” will based on the findings establish and write a report for the owner and give suggestions accordingly.
- JAQUET AG experts can use stored files from the MDS4500 units for further analysis and effective reports.

The Expert System



Files captured from the speed signals of the analysed engine will be processed and displayed in 4 typical plots.

The Expert System

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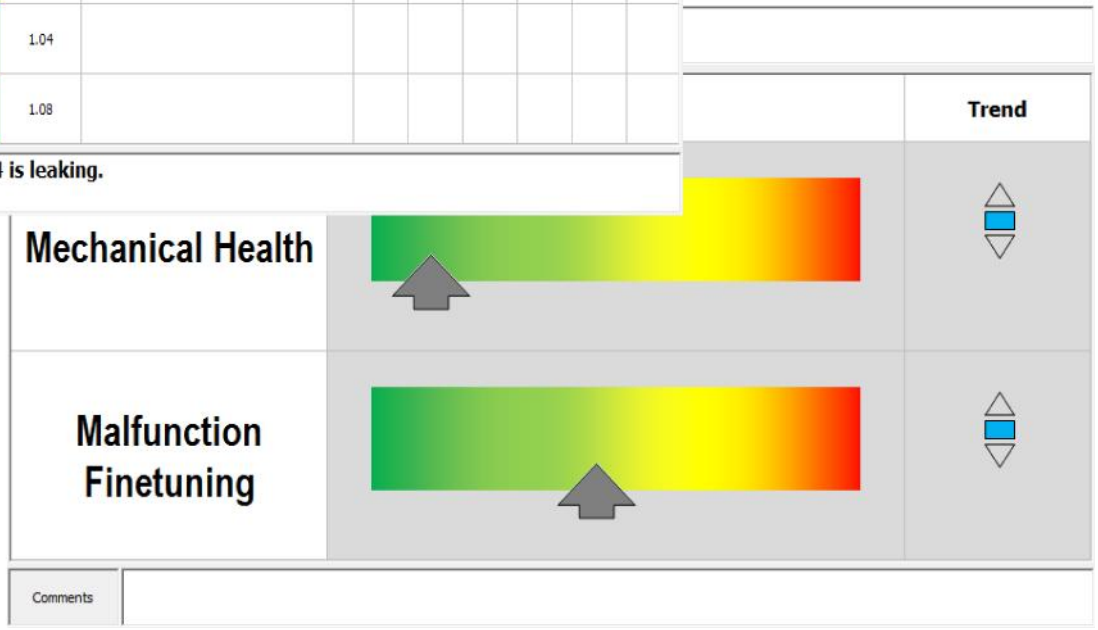
Conditions:	The engine is showing an injection problem. As a consequence the bearings are uneavenly loaded.

Curve	Indicator	Alarm	Variation	Comments	1	2	3	4	5	6
	Compression	0.04	1.67							
	Injection	0.74	1.14							
	Bearing	0.45	1.24							
	Combustion	0.08	1.46							
	Cam&Pumps	0.16								
	Friction	2.45	1.04							
	Irregularity	2.07	1.08							

Comments:	Injection line on cylider 4 is leaking.



Further the findings can be shown in easy to understand graphical overviews and displays which are very useful to create reports for customers and engine owners

The product concepts

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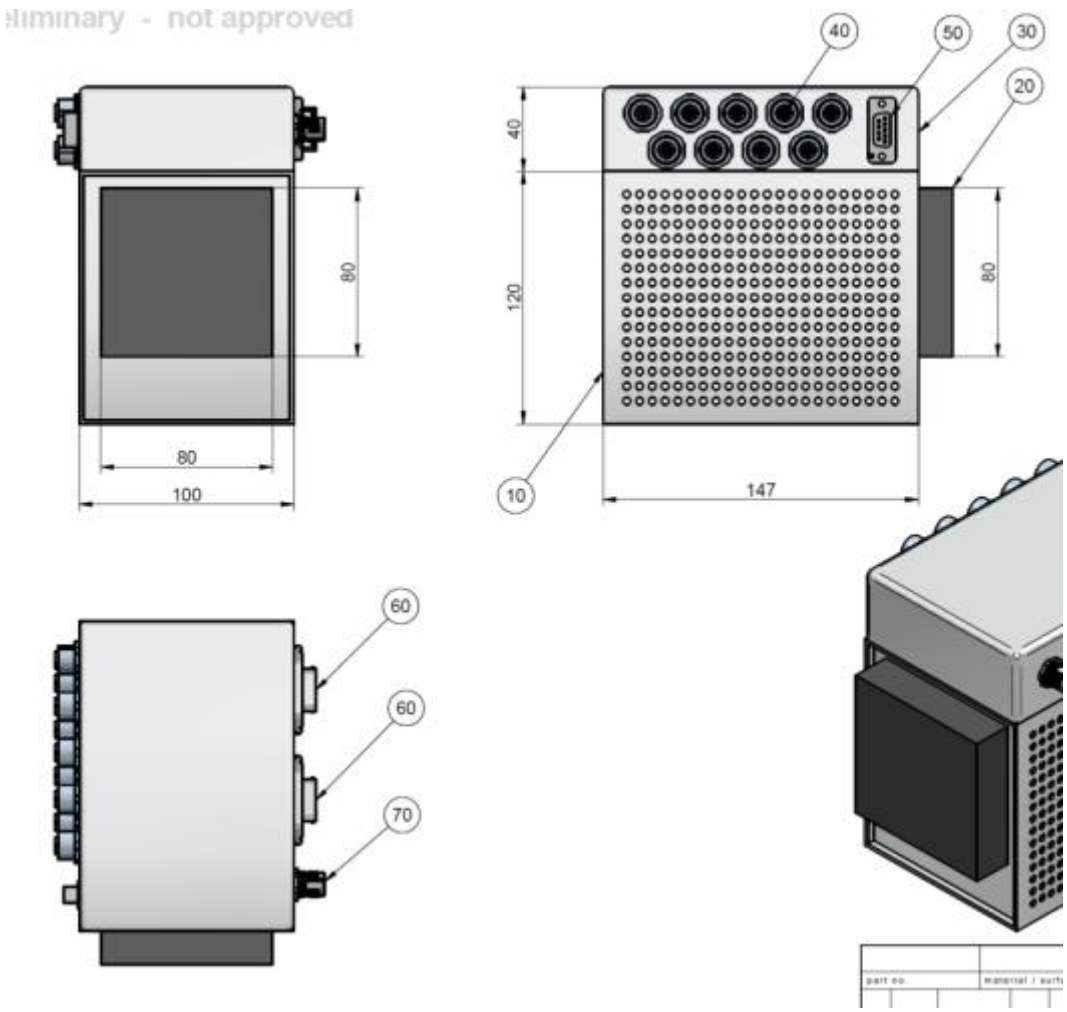
- **The «System for the Experts»**
  The PC-Windows based software VIB360 allows an expert to deeply analyze engines, rotating equipment like turbines, compressors, windmills and gear-boxes. The delivered results can be used to establish precise and well-founded reports for the users and owners of the equipment in question.
- **The «Embedded diagnostic system MDS 4500»**
  Embedded systems monitor engines during normal operational use. They allow to react in time based on precise information and warning signals. The results can be delivered in various ways – depending on the monitoring and maintenance concept of the user.

The “Embedded System”

- Designed to be installed right on the engine that needs to be monitored the embedded system contains the elements to run and work independently.
- The unit is built in a robust metal housing, having connector interfaces for the sensors, the supply voltage and auxiliary circuits.
- The unit is programed to monitor the engine real-time and store the analysed results. It can also transfer the data to a remote service - or fleet management.
- In the event major damage is likely to occur the unit can locally alarm the operating personnel or even stop the engine automatically if so desired.

MDS 4500 The Hardware

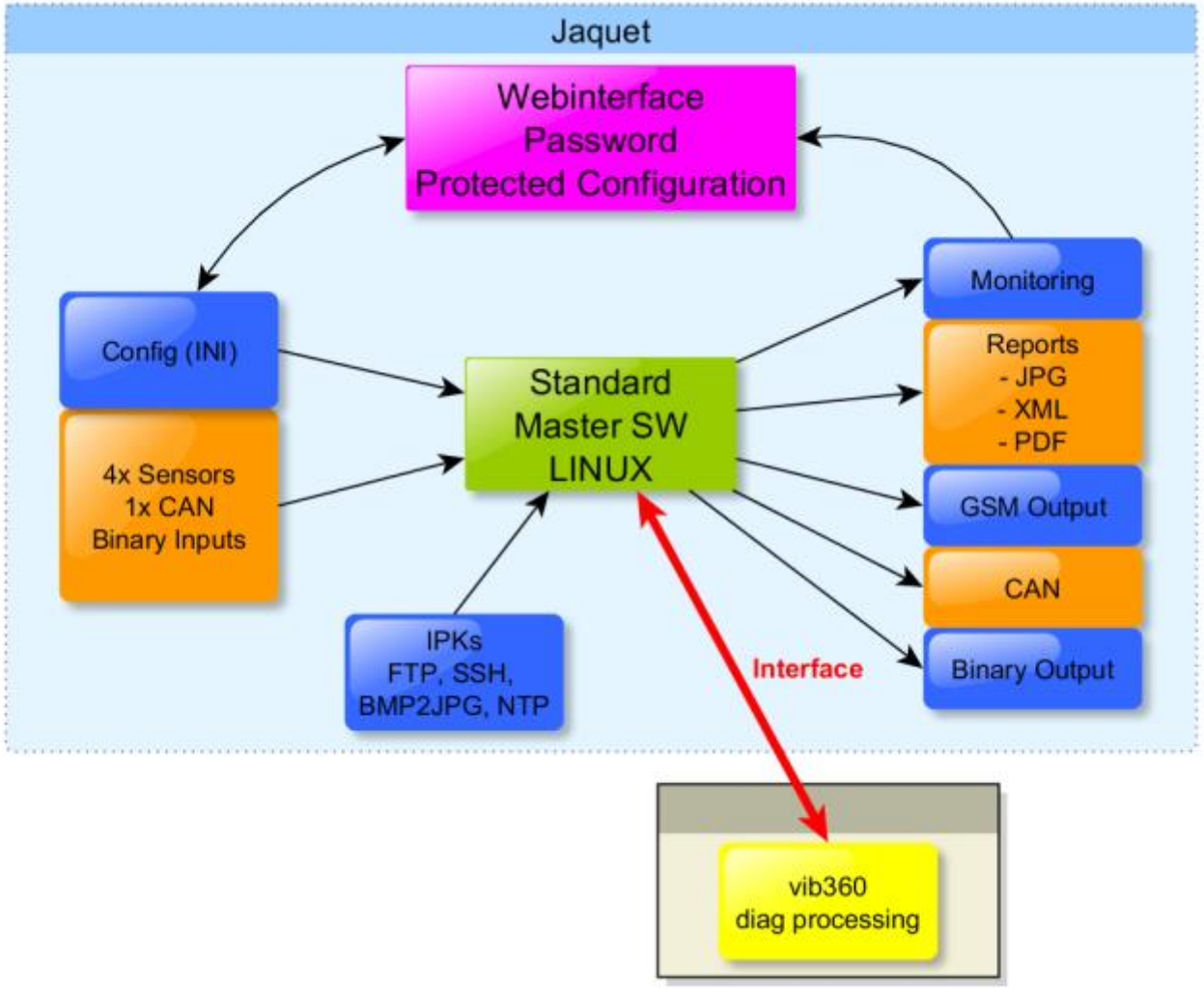


	Name	No
10	MDS 4500	1
20	SSD Hard-Disk	
30	Cover	1
40	Pos	9
50	CAN D-Sub 9-pole	1
60	RJ45 Connector	2
70	Industrial USB	1

Architecture of the “Embedded System”

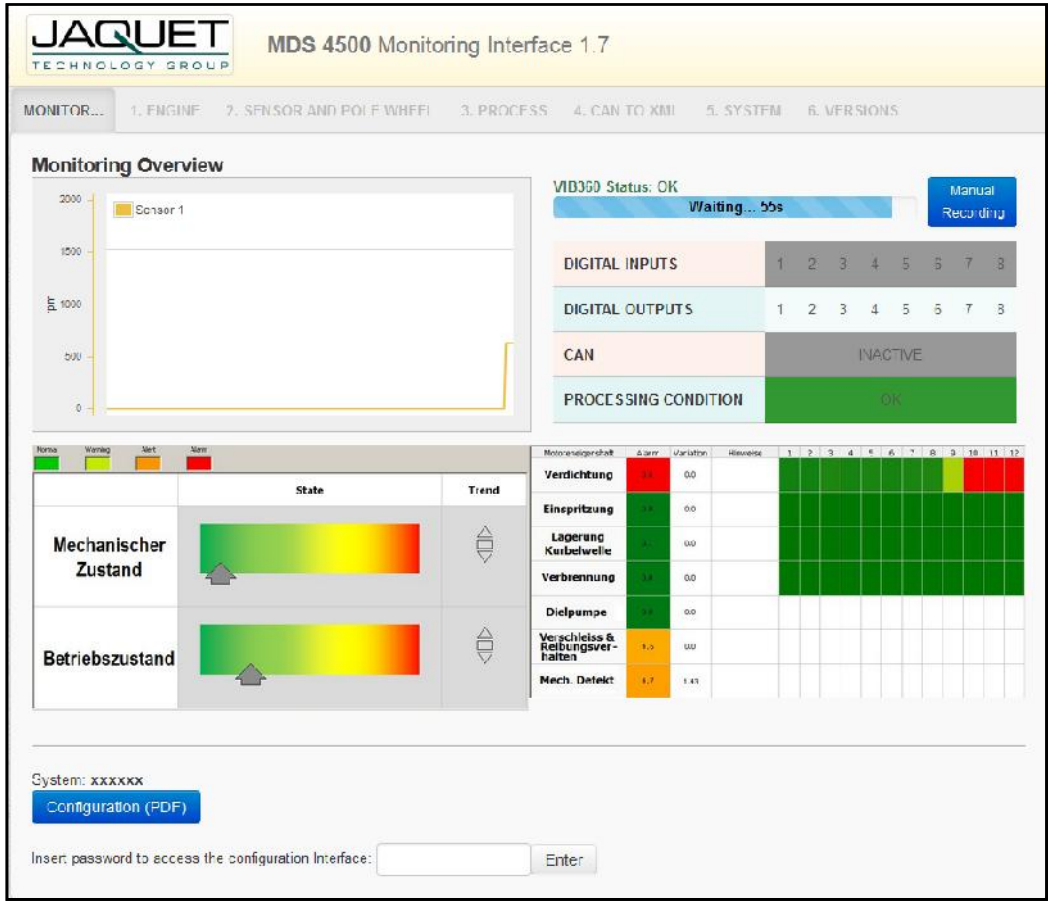
- MDS4500
  - ARM Cotrex A8 720 MHz
  - 256 MB DDR2-Ram
  - Disk Space 1 GB Flash file system
    128 GB memory (USB)
  - Ethernet
  - CAN 2.0 CANopen
  - 8 digital inputs
  - 8 digital outputs
  - 4 inputs for speed sensors
  - 24 VDC Power supply
  - OS: LINUX
  - Webserver available

MDS 4500 The Software concept



MDS 4500 The Monitoring interface

- Once connected with the browser of your PC the MDS4500 will display the “Monitoring Interface”:
  - Display real-time information of the connected sensors
  - Inputs and outputs, processing status and condition.
  - Display of the latest captured and processed diagnose results
- Start and control of service functions like configuration of the system and firmware update.



MDS 4500 Software The Configuration

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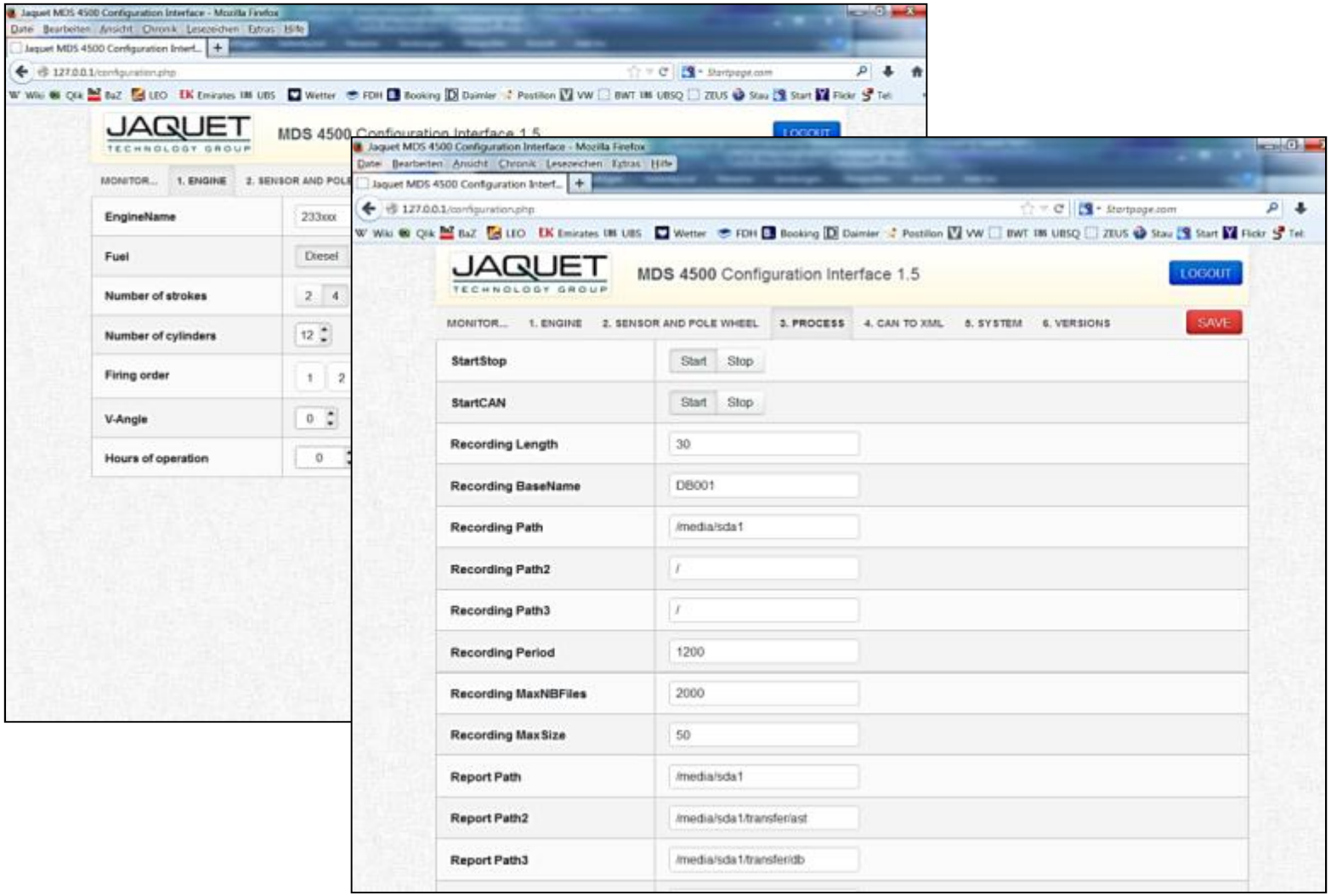

MDS 4500 Software The Configuration

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Name	Value
[ENGINE]	
EngineName	233xxx
Fuel	Diesel
Number_of_strokes	4
Number_of_cylinders	12
Firing_order	
V-Angle	
Hours_of_operation	
[SENSOR and POLE WHEEL]	
Sensor_1.used	
Sensor_1.name	
Sensor_1.ticks_per_revolution	
Sensor_2.used	
Sensor_2.name	
Sensor_2.ticks_per_revolution	
Sensor_3.used	
Sensor_3.name	
Sensor_3.ticks_per_revolution	
Sensor_4.used	
Sensor_4.name	
Sensor_4.ticks_per_revolution	
Recording_Rule1.speedMax	10000
Recording_Rule1.speedChange	100
Recording_Rule1.waitingTime_stability	100
Recording_Rule1.waitingTime_nextRecord	1000
Recording_Rule1.speedUnstable_doNotRecord	0
Recording_Rule1.speedUnstable_acceptableSpeedVariation	20
Generation1_ChannelNum	
Generation1_SpeedRefChannel	
Generation1_MinRPM	
Generation1_Process1.Type	
Generation1_Process1.OtChan	
Generation1_Process1.CrankShaft	
Generation1_Process1.OtherChan	
Generation1_Process1.Rigidity	
Generation1_Process1.ZeroDegree	
Generation2_ChannelNum	
Generation2_SpeedChannel	
Generation2_MinRPM	
Generation2_ThresholdType	
Generation2_ThresholdLow	
Generation2_ThresholdHigh	
Generation2_Process1.Type	
Generation2_Process1.OtChan	
Generation2_Process1.CrankShaft	
Generation2_Process1.OtherChan	
[PROCESS]	
StartStop	Start
StartCAN	Start
Recording_Length	30
Recording_BaseName	DB001
Recording_Path	/media/sda1
Recording_Path2	/
Recording_Path3	/
Recording_Period	1200
Recording_MaxNBFiles	2000
Recording_MaxSize	50
Report_Path	/media/sda1
Report_Path2	/media/sda1/transfer/ast
Report_Path3	/media/sda1/transfer/db
Report_csv	0
Report_xml	1
Report_jpg	1
Recording_Rule1.channelNum	2
Recording_Rule1.speedMin	350

The product concepts

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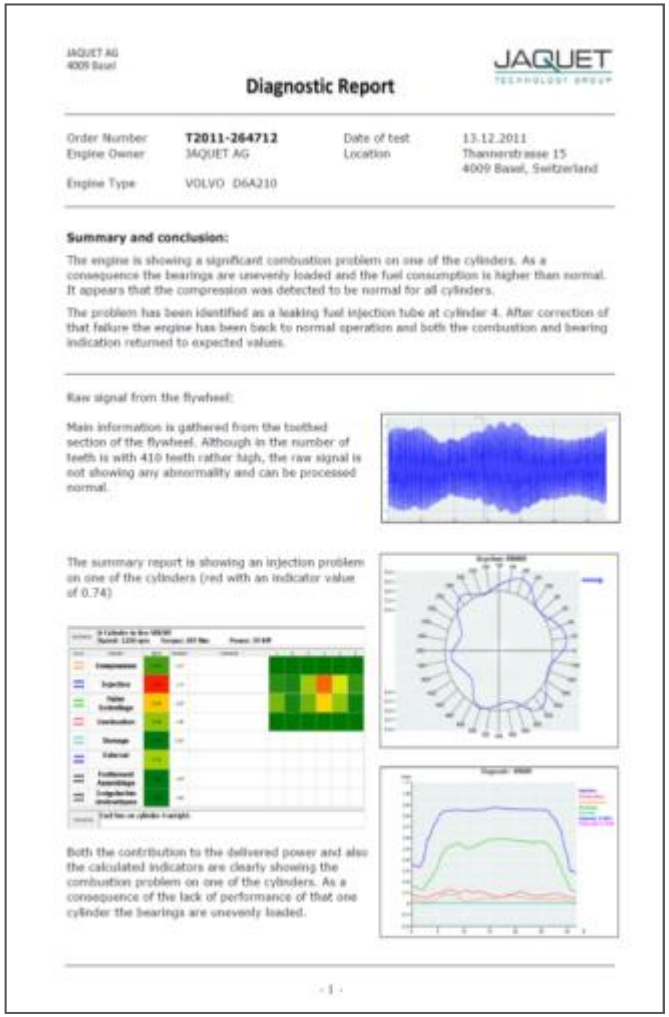
- **The Service – Unit / The Diagnostic Service**
  The MDS4500 system can also be successfully used as a service unit. With the setup program the engine to be analyzed will be tailored and the unit basically serves as a data acquisition system. Immediate results are shown in the monitoring interface window. The captured and stored data can be analyzed off line. Results are delivered in form of a clear and detailed report.

The Diagnostic Service



JAQUET AG
4009 Basel

JAQUET TECHNOLOGY GROUP

Diagnostic Report

Order Number	**T2011-264712**	Date of test	13.12.2011
Engine Owner	JAQUET AG	Location	Thannerstrasse 15 4009 Basel, Switzerland
Engine Type	VOLVO D6A210		

Summary and conclusion:

The engine is showing a significant combustion problem on one of the cylinders. As a consequence the bearings are unevenly loaded and the fuel consumption is higher than normal. It appears that the compression was detected to be normal for all cylinders.

The problem has been identified as a leaking fuel injection tube at cylinder 4. After correction of that failure the engine has been back to normal operation and both the combustion and bearing indication returned to expected values.

Raw signal from the flywheel:

Main information is gathered from the toothed section of the flywheel. Although in the number of teeth is with 410 teeth rather high, the raw signal is not showing any abnormality and can be processed normal.

The summary report is showing an injection problem on one of the cylinders (red with an indicator value of 0.74)

Both the contribution to the delivered power and also the calculated indicators are clearly showing the combustion problem on one of the cylinders. As a consequence of the lack of performance of that one cylinder the bearings are unevenly loaded.

- 1 -

- The customer buys and installs the data acquisition hardware and software to capture data from the engine to be monitored.
- In case the customer uses the MDS4500 as a service unit, a preliminary analysis GYR-chart is delivered. Data of the engine is stored in the system and can be sent to the specialists at JAQUET for an in depth analysis.
- In cases where the system is installed on the engine at regular intervals– (i.e. every week) the report can be generated and sent back to the customer, thus enabling the formation of a plan for the necessary maintenance in a a very cost efficient way.

Possible Results

- Preventive maintenance can be expensive. The experience at Deutsche Bahn is that 50% of the replaced injectors would have been still o.k. to use.
- Major damage doesn’t occur without early warning. MDS4500 provides the right sensing and analysis to detect faults at an early stage.
- Fuel consumption and more available service hours however, are the most important saving effects of the MDS4500. If one cylinder is under-performing normally the governor will compensate for the loss of power, but at the cost of increased fuel consumption…

Diesel engine test bench @JAQUET

- A test cell with a 6 cylinder Volvo engine is available at JAQUET
- Tests with diagnostic systems, proof of concept and demonstration of software results can be performed

Diesel engine test bench @JAQUET

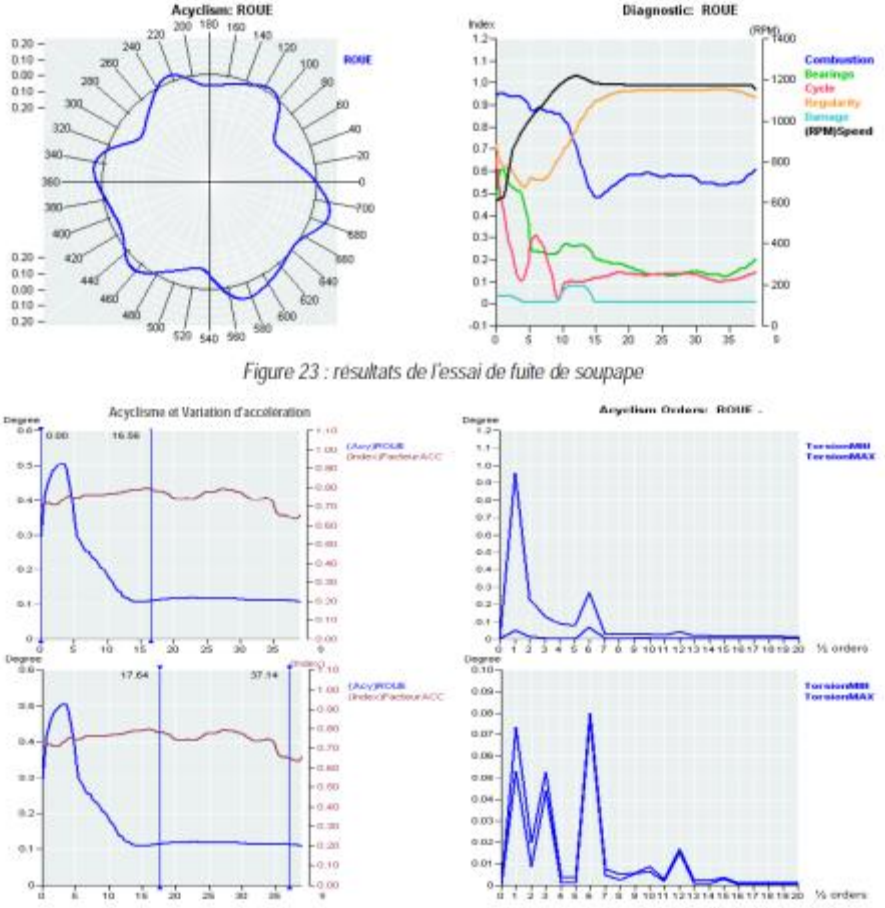
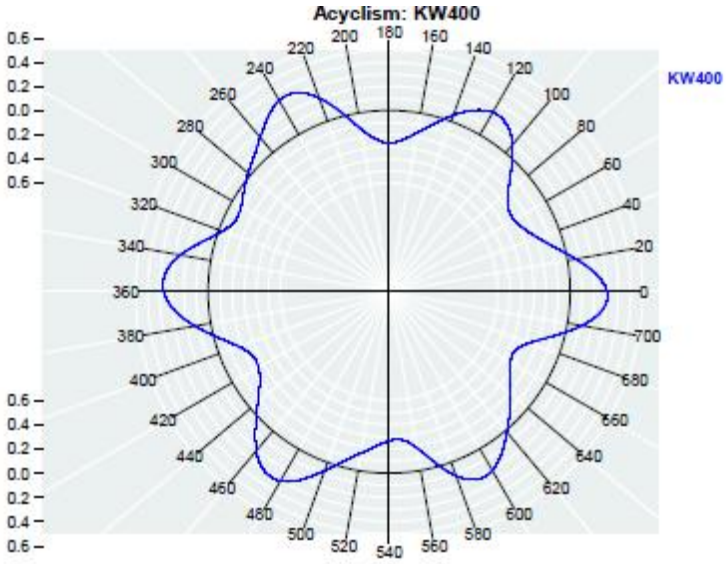
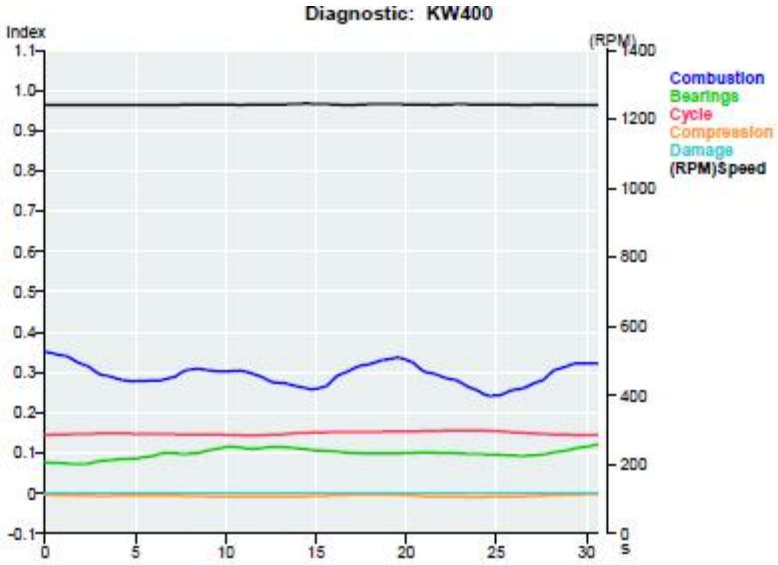


Figure 23 : résultats de l'essai de fuite de soupape

- Intensive tests with all kinds of failure simulations can be performed to prove and validate the software tools

Delivered Information



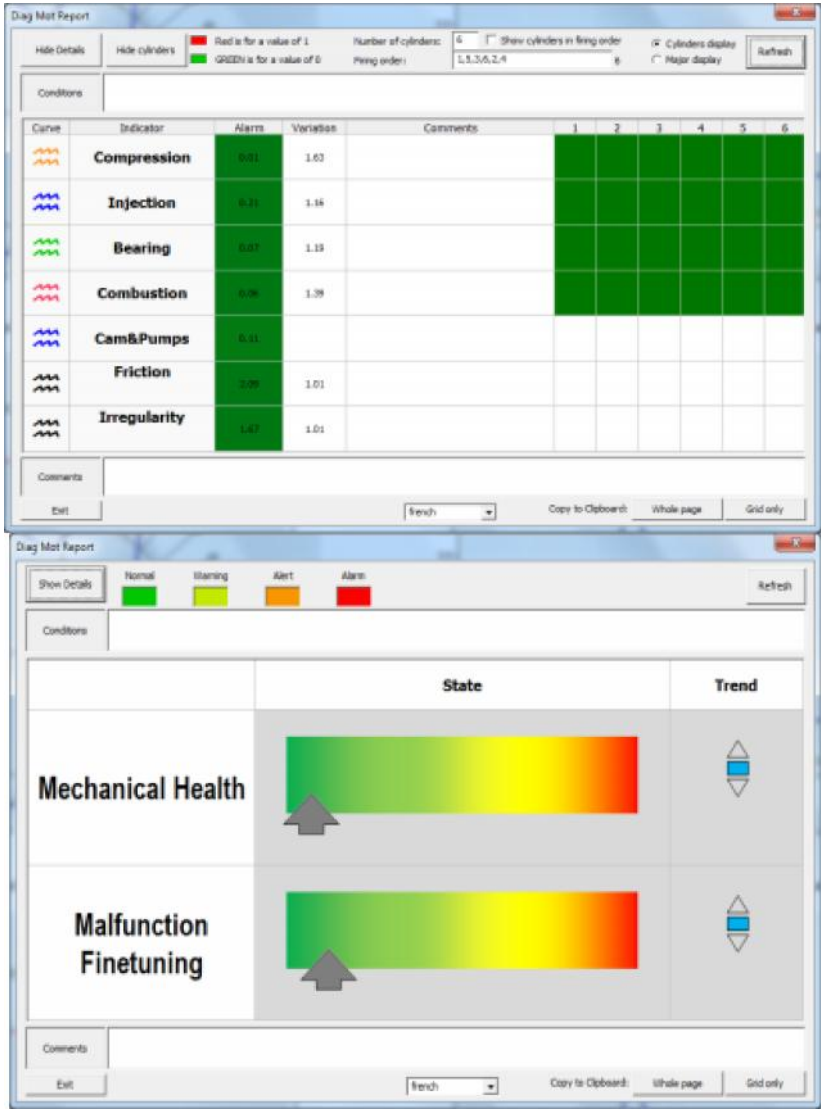


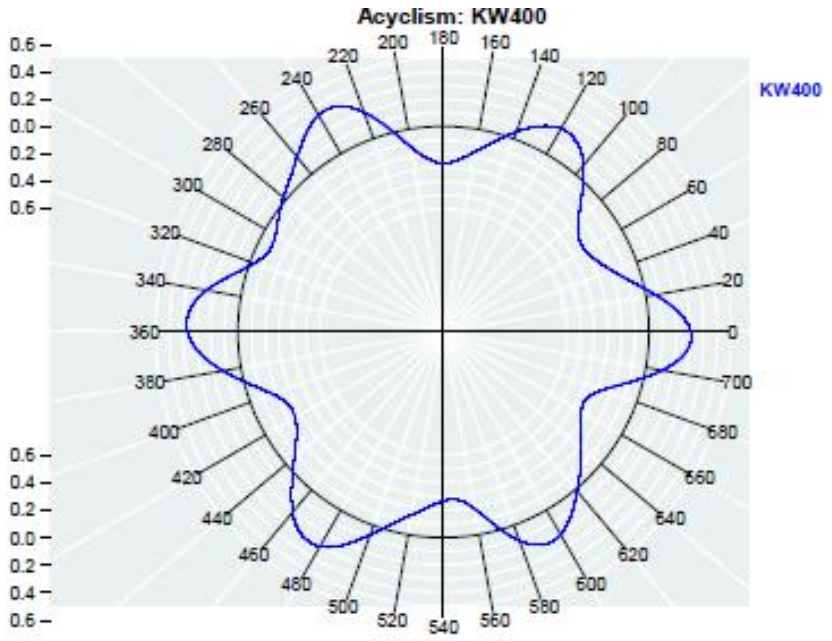
- 6 Cylinder Volvo Diesel engine

Speed:	1250 min-1
Torque:	297 Nm
Power:	39 kW

Currently running under normal condition . Combustion, bearing load, compression and a-cyclic behaviour of the mechanical components are all in normal range

Delivered Information

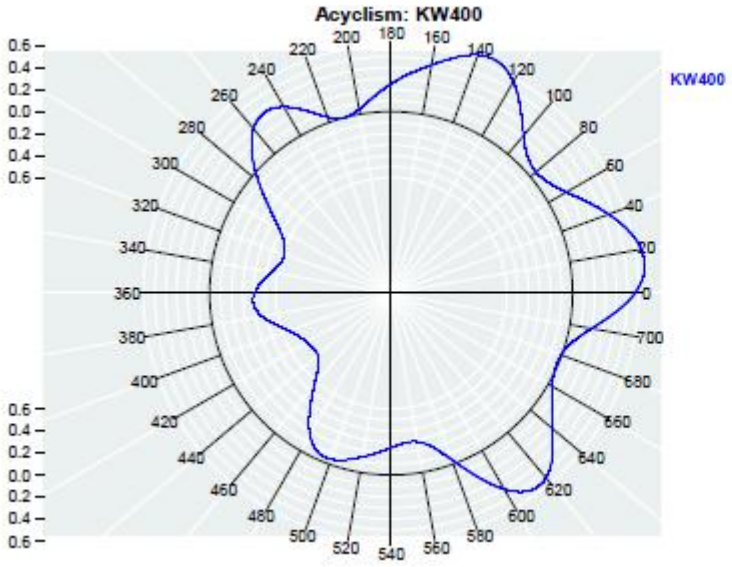


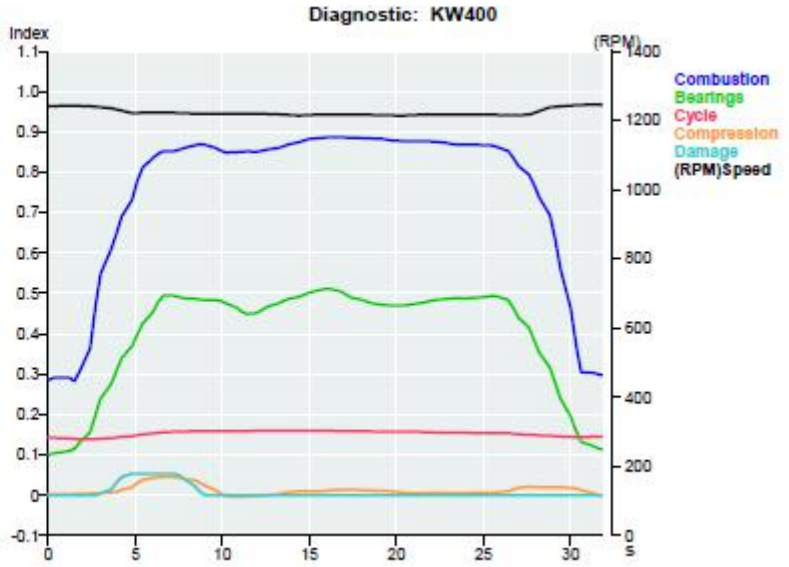


6 Cylinder Volvo Diesel engine

- At normal condition the GYR indicators are showing “green” conditions for all cylinders and for the overall performance.

Delivered Information



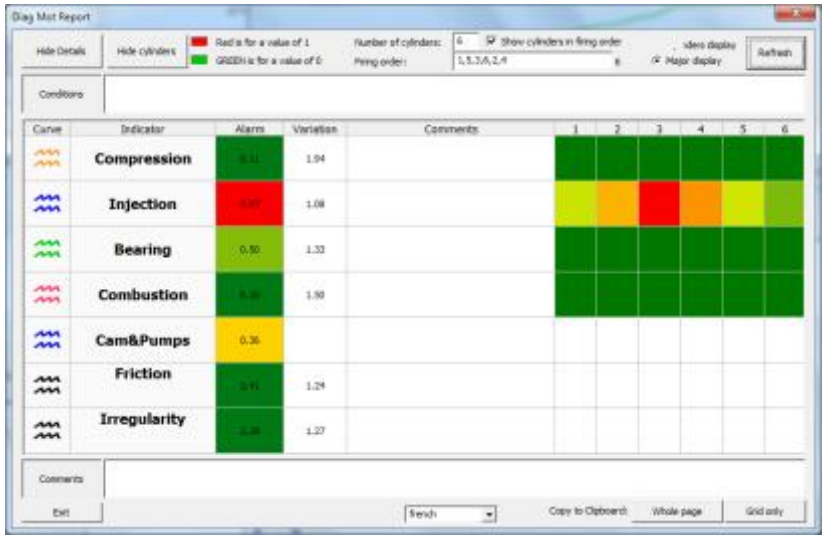


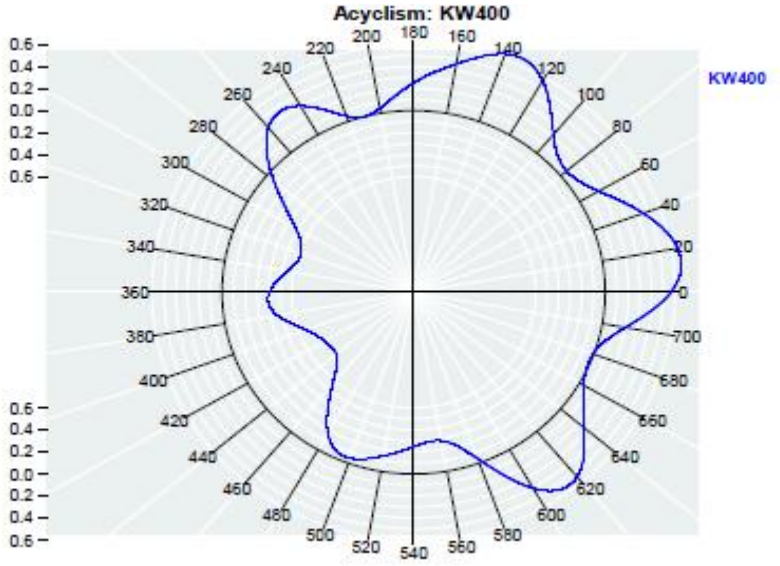
- 6 Cylinder Volvo Diesel engine (reduced fuel injection at C1)

  Speed: 1250 min-1
  Torque: 297 Nm
  Power: 39 kW

  Thus dramatically distorted combustion indication, as a consequence the bearing load is also effected, compression and a-cyclic behaviour of the mechanical components on the other hand are still in normal range.

Delivered Information





6 Cylinder Volvo Diesel engine

- The GYR report indicators are clearly reacting on the introduced injection problem.
- Cylinder (Nr. 3) is affected and the reason is indicated as a injection problem with a link also to the injection pump
- The overall indicators are showing no mechanical damage but a general decrease in the functionality of the engine.

Possible Results

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Overview	Description	Remarks
Fuel injection	Limited functionality of fuel injection incl. its breakdown (for each cylinder)	Lack of fuel delivery for each cylinder can be detected including the total loss of fuel delivery
Fuel injection nozzle	Limited functionality of fuel injection nozzle incl. its breakdown (for each cylinder)	Lack of fuel delivery for each cylinder can be detected including the total loss of fuel delivery
Fuel injection pump	Limited functionality of injection pump incl. its breakdown (for each cylinder)	Lack of fuel delivery for each cylinder can be detected including the total loss of fuel delivery
Leakage of nozzle	Limited functionality and leakage of nozzle line (for each cylinder)	
Injection control	Limited functionality of the injection control system incl. its breakdown (for each cylinder)	
Compression	Limited functionality of compression within the cylinder (for each cylinder)	Lack of compression for each cylinder can be detected
Compression cylinder/piston	Loss of compression within a cylinder caused by the cylinder/piston combination (for each cylinder)	Leakage of the piston rings, etc
Compression valves	Loss of compression within a cylinder caused by the valves (for each cylinder)	Problems with the cylinder head
Friction	Changes in the coefficient of friction between piston and cylinder (for each cylinder)	Performable by turning off and coasting of the motor
Speed variation	Extreme speed variations of the turbocharger	
Bearing	Changes of the coefficient of friction in the bearing of the rotor of the turbocharger	

Delivered Information

ID	Code gelb	Code rot		Schaden	Realisierung	
1	0611 - 0616 061A - 061F	0711 - 0716 071A - 071F	A1-6 B1-6	Funktionseinschränkung der Einspritzanlage inkl. deren Ausfall (je Zylinder)	mangelnde Kraftstoffzufuhr je Zylinder kann detektiert werden	Muss
2	0621 - 0626 062A - 062F	0721 - 0726 072A - 072F	A1 B1-6	ktionseinschränkung		
3	0631 - 0636 063A - 063F	0731 - 0736 073A - 073F	A1-6 B1-6	Funkti (je Zylinde		
4	0641 - 0646 064A - 064F	0741 - 0746 074A - 074F	A1-6 B1-6	Funktionseinschr Zylinder)		
5	0651 - 0656 065A - 065F	0751 - 0756 075A - 075F	A1-6 B1-6	Funktionseinschränkung (je Zylinder)		
6	0661 - 0666 066A - 066F	0761 - 0766 076A - 076F	A1-6 B1-6	Funktionseinschränkung Zylinder)		
7	0671 - 0676 067A - 067F	0771 - 0776 077A - 077F	A1-6 B1-6	Veränderung der Kompr Paarung Kolben / Zylinc		
8	0681 - 0686 068A - 068F	0781 - 0786 078A - 078F	A1-6 B1-6	Veränderung der Kompr Ventilen (je Zylinder)		
9	0691 - 0696 069A - 069F	0791 - 0796 079A - 079F	A1-6 B1-6	Veränderung der Reibwerte der Reibpaarung Kolben / Zylinderlaufbuchse (je Zylinder)	erfüllbar, durch Abschaltung und Auslauf des Motors	Muss
10	0601	0701		Starke Drehzahlschwankungen des Abgasturboladers	erfüllbar	Muss
11	0602	0702		Veränderung der Reibwerte in der Lagerung des Rotors des Abgasturboladers (Schwergang)	erfüllbar, durch Abschaltung und Auslauf des Motors	Muss
12	06Ax...	...06Cx		20 Meldungen vom Heinzmannregler		

071B 22.09.2007 174426

Failure code Date of registration Time

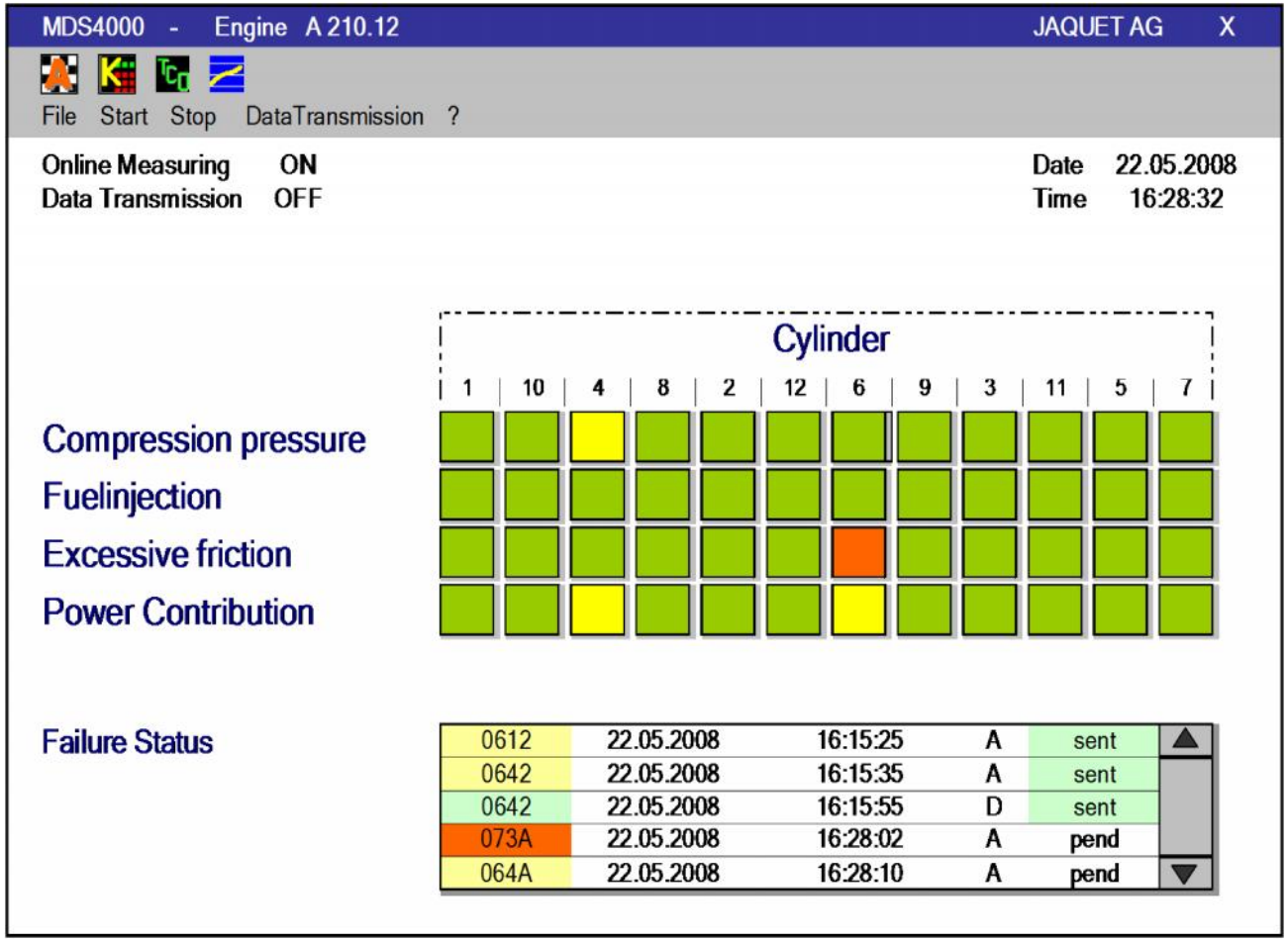
07 = severe failure

1 = malfunction of the injection system

B = 2nd cylinder of the B-bank

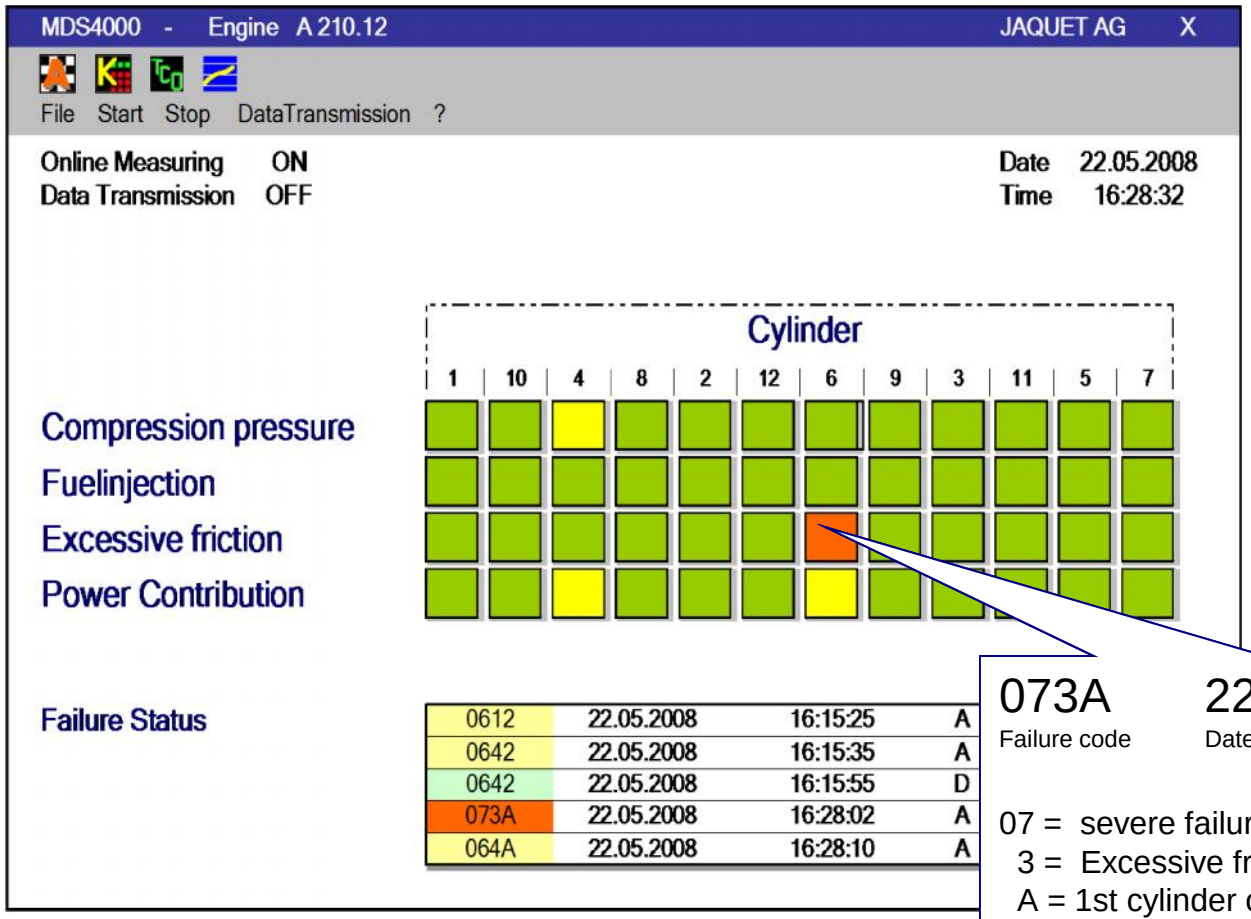
A different way of indication can be a failure code which indicates a problem. This code will stored (may be together with a date and time stamp) or transmitted to a control-center. (This example is for a 12 Cylinder engine)

Possible indication of a failure



Indication of a detected failure can be done by a matrix.

Possible indication of a failure



Indication of a detected failure can be done by a matrix.

The failure code can be stored (may be together with a date and time stamp) for immediate inspection.

Or it can be transmitted to a control-center by a can-bus interface or trough GSRM.

073A
Failure code

22.05.2008 162802
Date of registration Time

07 = severe failure
3 = Excessive friction
A = 1st cylinder of the B-bank

Tests performed at “L’Adroit”

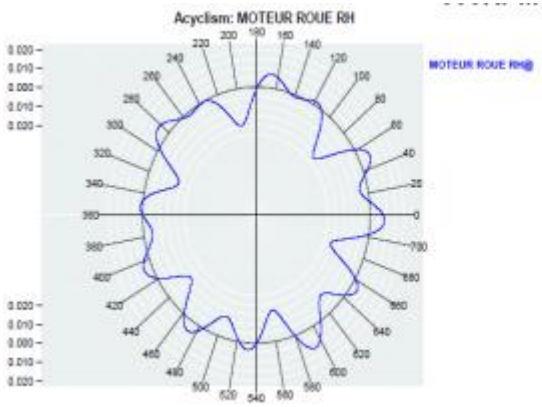
- The brand new French Vessel l’Adroit is equipped with 2 12 cylinder main engines of ABC.
- It is the aim of DCNS – the constructor of the boat – to install a condition monitoring system on board in order to closely monitor the behaviour of the engines.

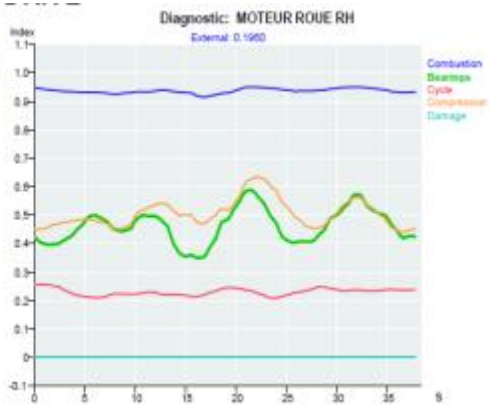
Tests performed at “L’Adroit”

- In a measuring campaign of one day the engines have been tested and many data files have been stored.
- The data has been analysed with the aim to find the ideal settings for the pending installation and to prepare a presentation for the customer to justify the investment.

Tests performed at “L’Adroit”

- Data captured during the test day has shown some weakness of the engines under partial load – this is subject of further investigation at the moment.
- Combustion regularity increases with more load – it is obviously optimised for higher RPM performance points.





Tug-boats in the Rotterdam Harbour

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125 Years | 1889 – 2014

- Tug-boats in the Rotterdam Harbour are selling their pull-force and need to have a constant monitoring of the performance of their engines.
- Tests have confirmed the ability of the MDS to deliver the required information. Two fleets will be step by step equipped with the systems.

Emergency Pumps in Nuclear Power-Plants

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- The French Nuclear Power-Plants are equipped with 4 main emergency Diesel engines for the cooling system. Annually these engines must be tested and a performance report has to be generated.
- MDS 4500 helps to generate this report semi-automatically.

Emergency Pumps in Nuclear Power-Plants

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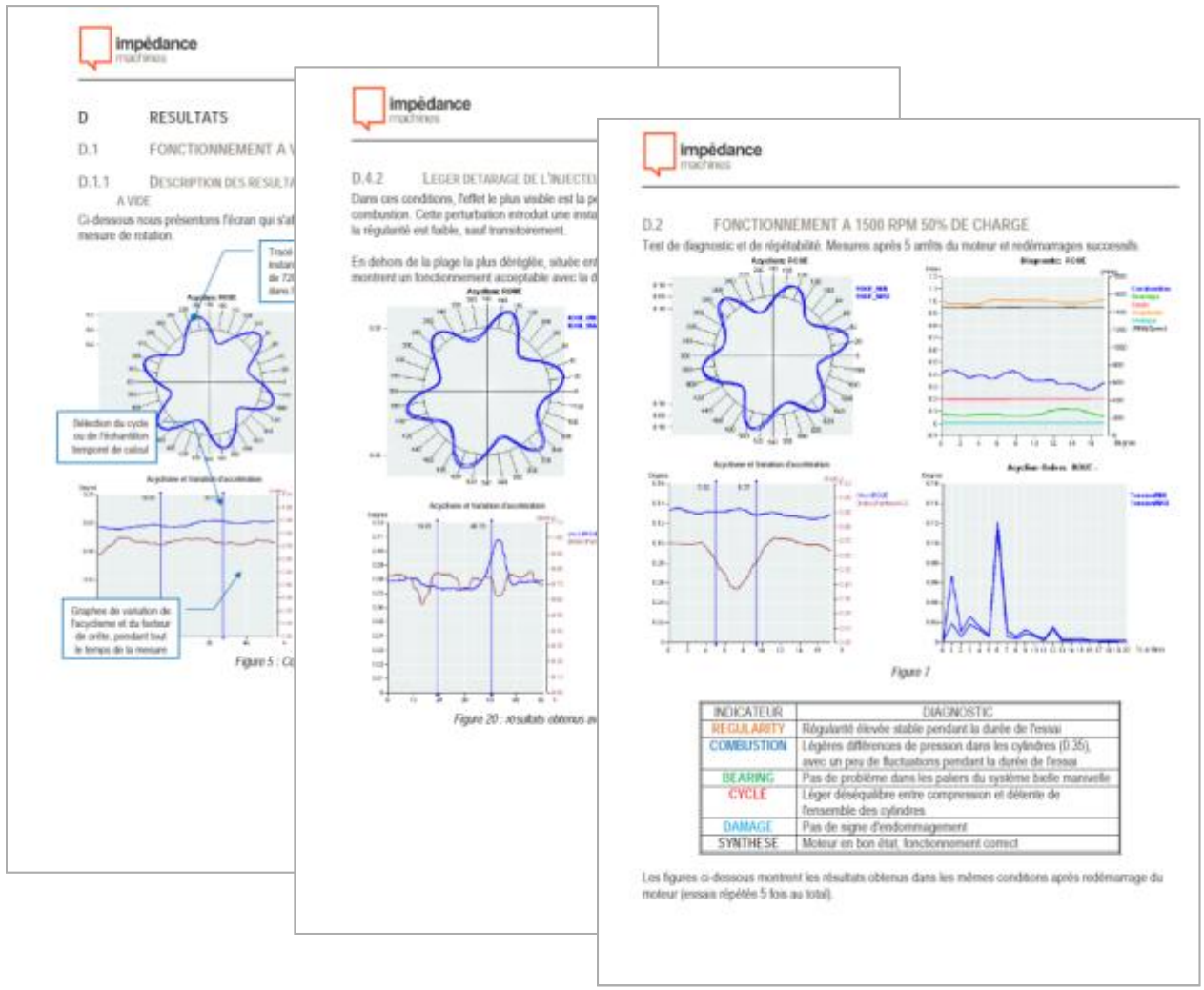
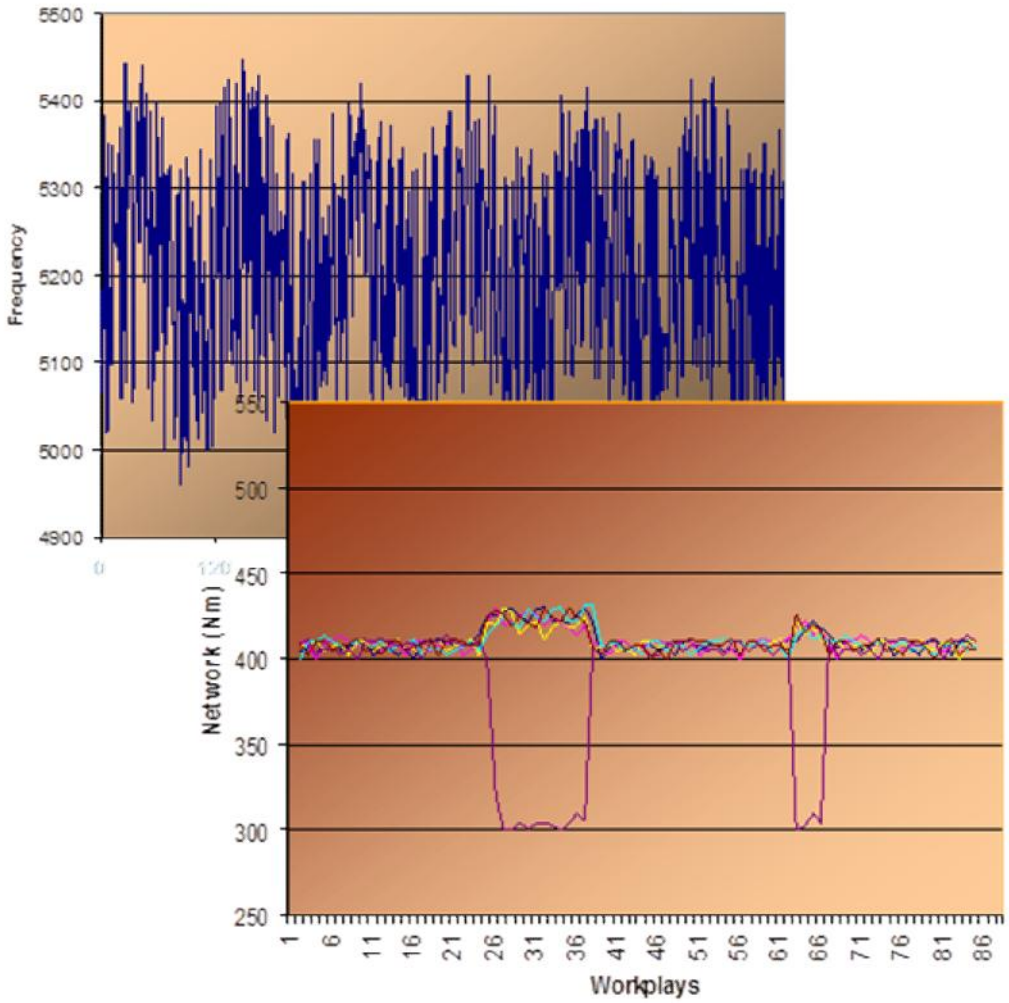


DB-Schenker Diesel freight loc BR233

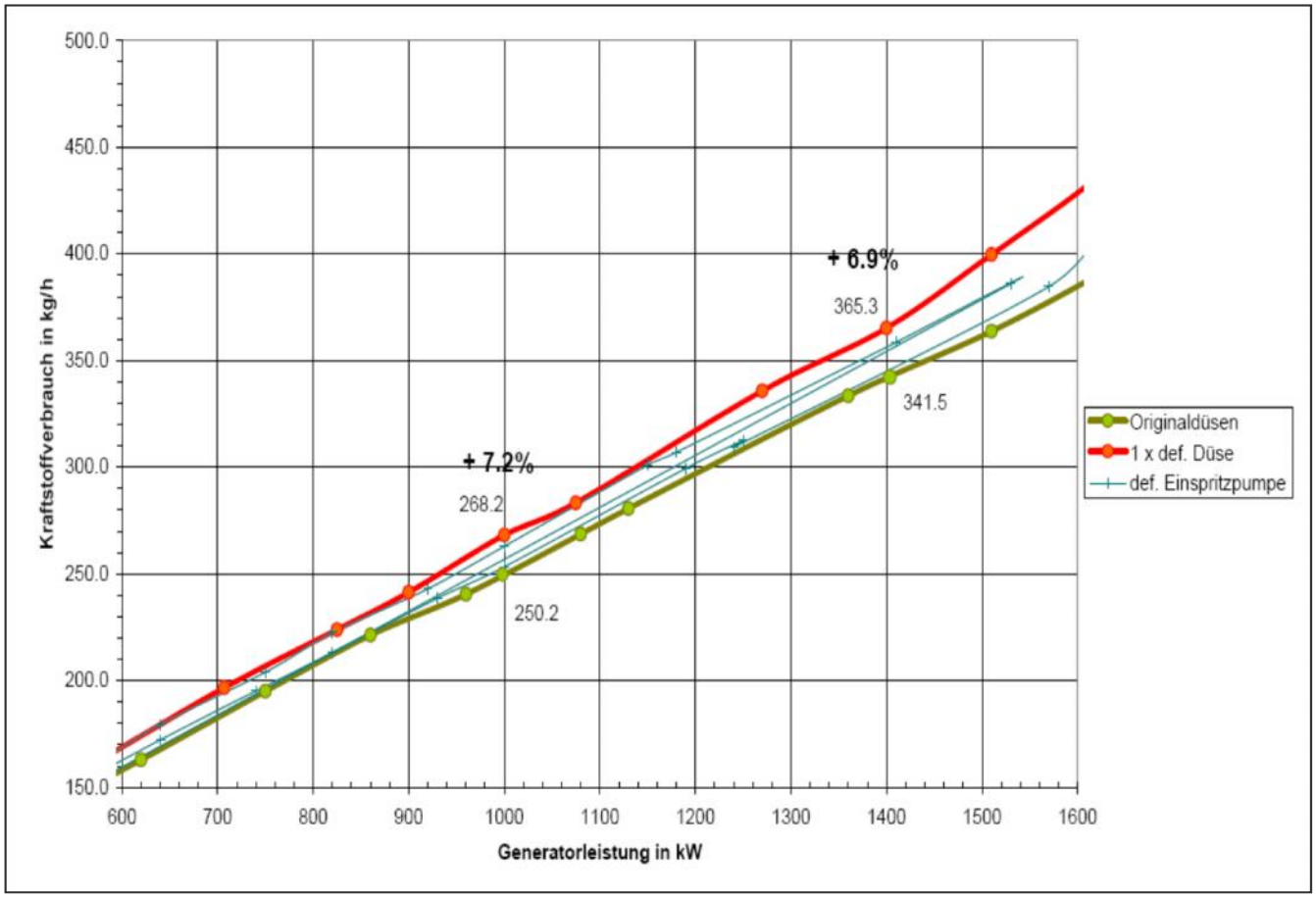
- This freight locomotive BR233 is equipped with a Russian 2 MW 12-cylinder diesel engine.
- Main reasons for the MDS4500:
  - Fuel savings trough better control of the condition of the injectors
  - Avoid of major damages
  - Optimizing and better planning of service and maintenance
  - Monitoring of the turbocharger

Excessive Fuel Consumption



- The most economical fuel consumption results from all cylinders contributing evenly to the engine output power.
- In a case where one cylinder no longer reaches its normal performance the governor system will normally compen-sate the power output by an increased contribution of the other cylinders.
- The result is more stress and thus less expected life time of the entire engine but even more important also an excessive fuel consumption.

Optimising Fuel Consumption



Tests on a 12 cylinder engine have proven that one defective injector can cause up to 7% of excessive fuel consumption of the engine even at partial load condition.

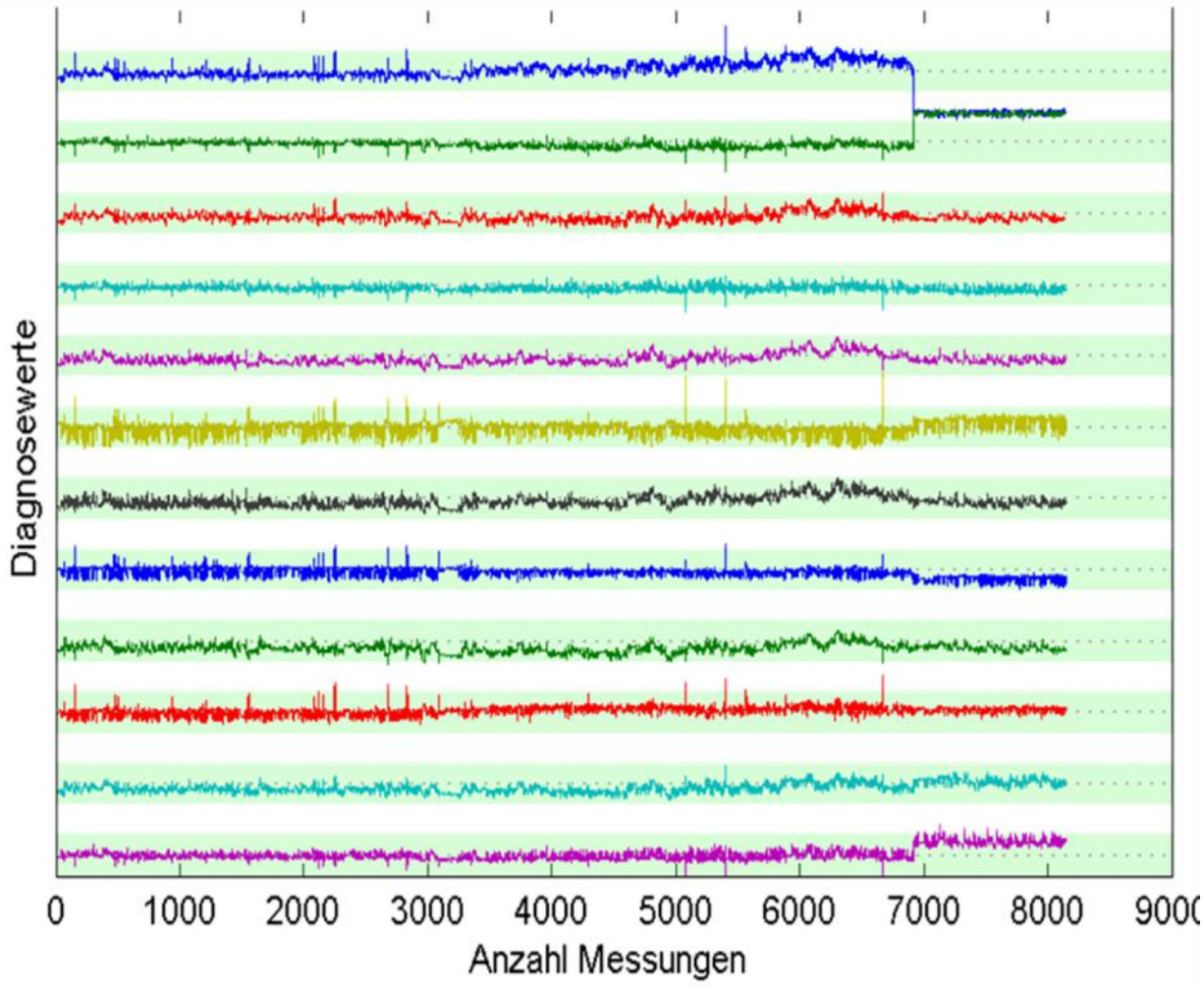
Avoiding Major Engine Defects

Such damage doesn't just happen without warning signals.

The experience at Deutsche Bahn has proven the effectiveness of the system.

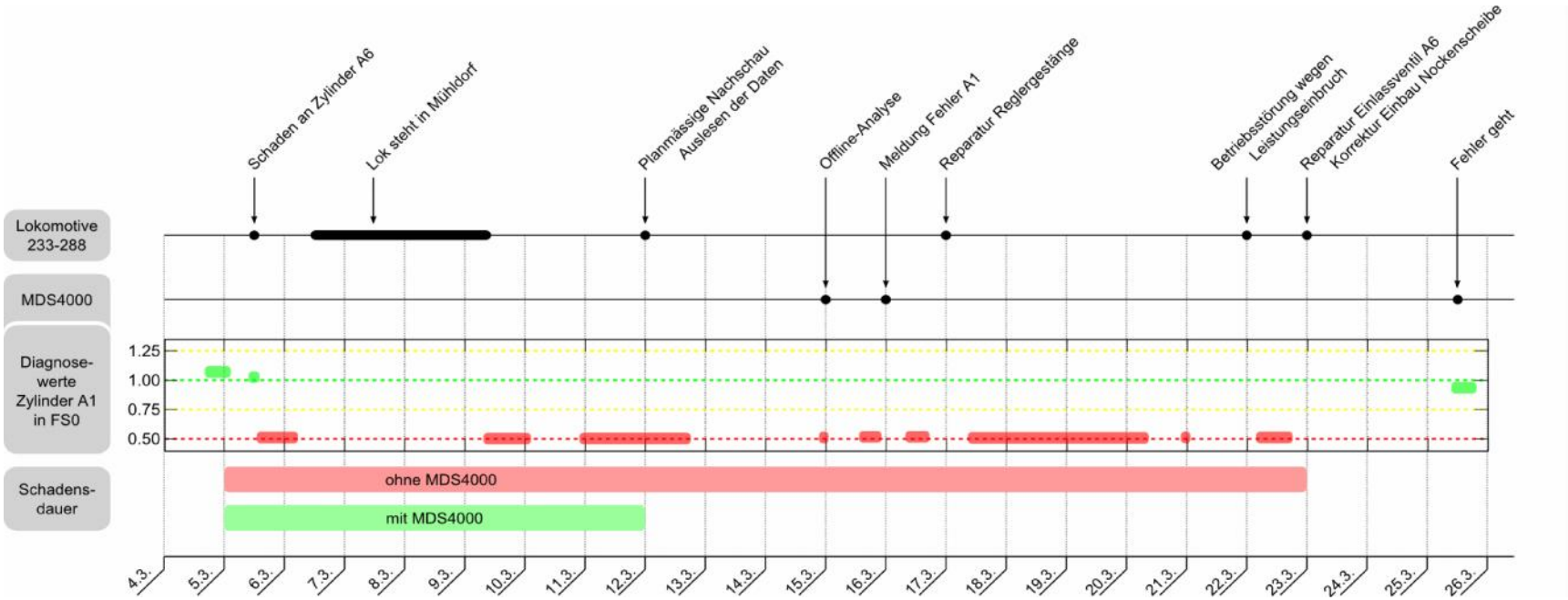
Although the engine has been used by professional and well trained personnel and the machine has been inspected during the development of the damage only the correct interpretation of the available data from the MDS monitoring system could have avoided an expensive exercise including a rescue from the track.

Avoiding major damages



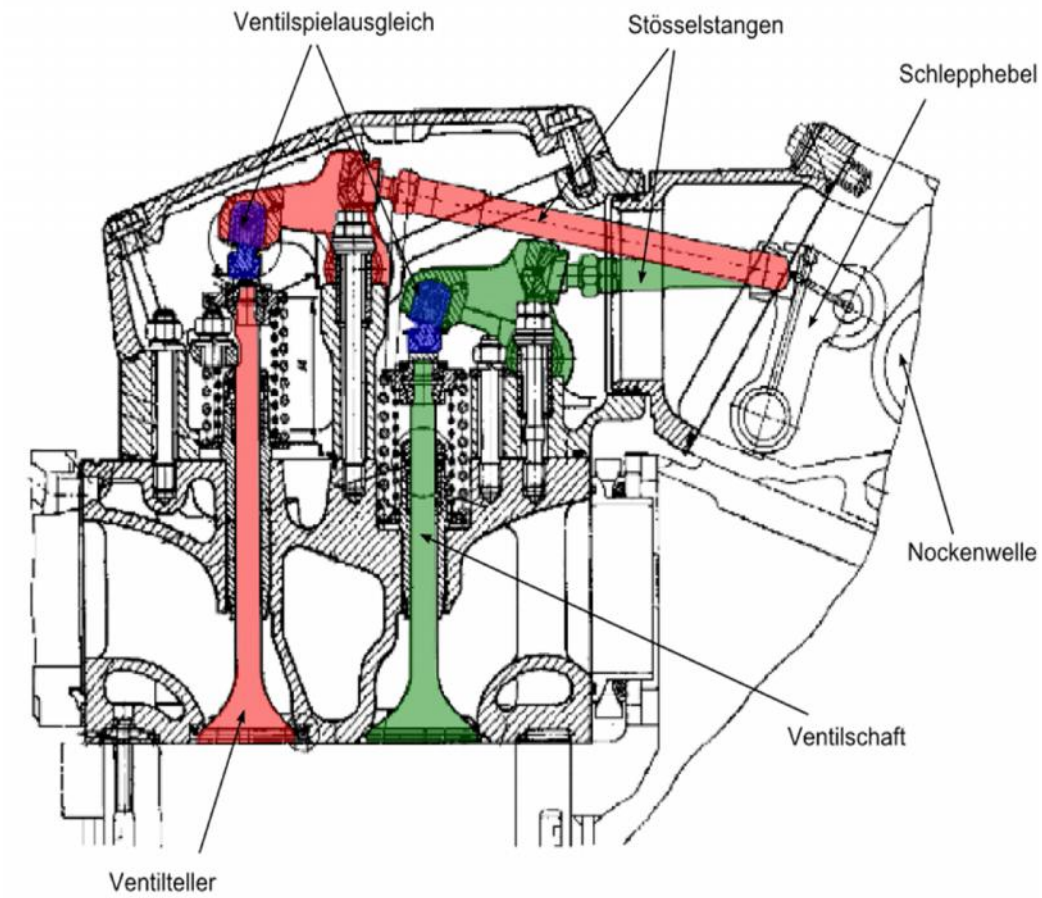
Chronological course of a major failure of a 12 cylinder diesel engine on a locomotive.

Development of a failure on the BR233-288



- The MDS detected a compression warning at 5.3.
- The engine was inspected but no fault was found. (Actually there was a broken valve spring, a minor problem at the time).
- The engine was put back in service at 9.3. The MDS continued to show warnings
- At 23.3. (15 days after initial diagnosis) the engine suffered a catastrophic failure and had to be rescued from the track
- The cylinder head and part of the piston had been damaged.

The root cause of the damage on the BR233-288



- A broken valve spring was preventing the exhaust valve from closing properly
- The valve eventually was hit by the piston
- The progression of this failure (from the first detectable occurrence to the final catastrophic failure) took about 20 days of fairly regular use of the engine.

The final state of the damage on the BR233-288

- As a consequence of not responding to the initial relatively minor problem serious damages to the cylinder-head, the connecting rod and the piston occurred.
- The cost for the repair of this single incident would have paid for the installation of MDS4500's on about half of the fleet.

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Don’t let your engine end like that –
Protect it with an MDS4500