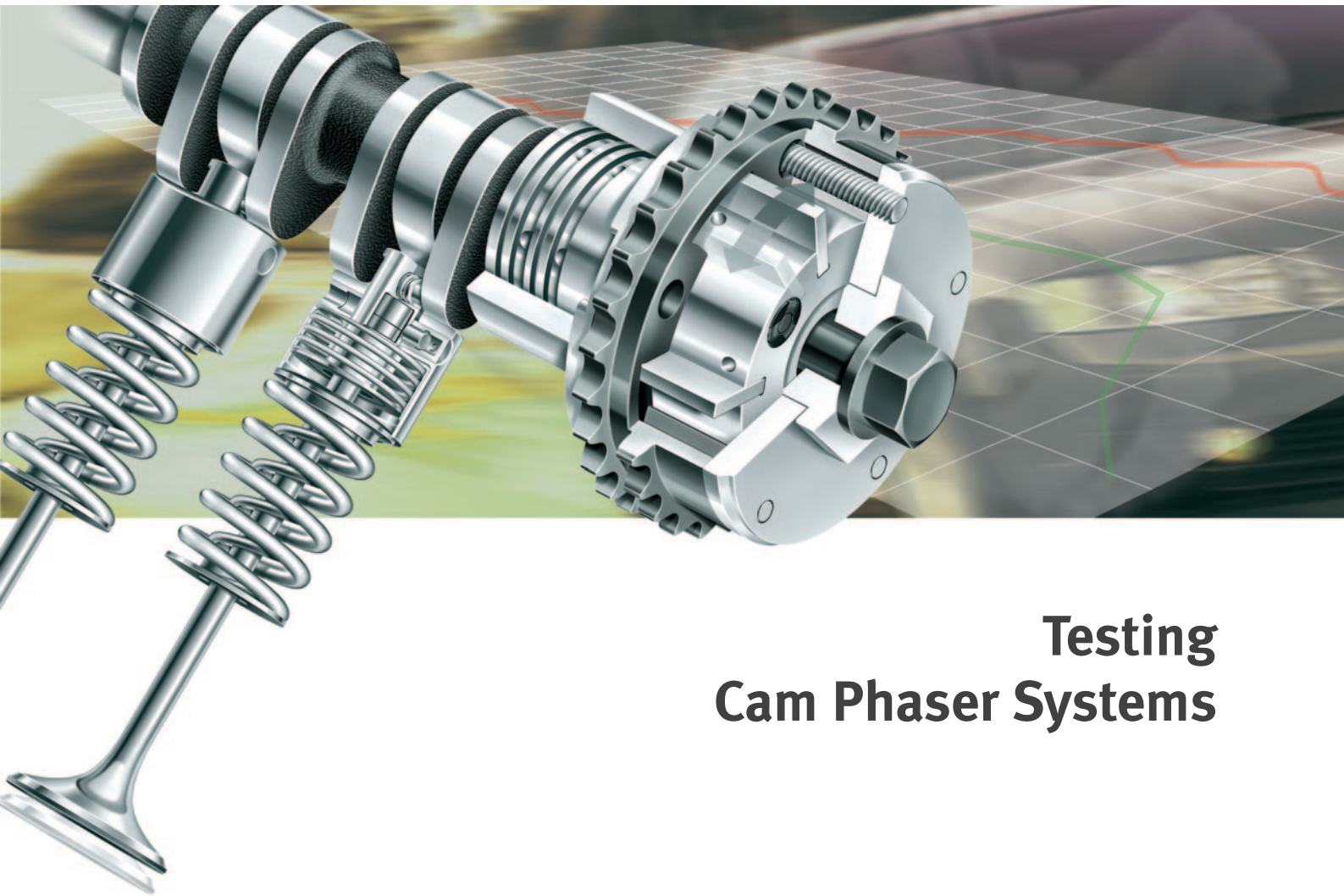

Testing
Cam Phaser Systems

A Member of the
Schaeffler Group

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Due to constant development of the product range, we reserve the right to make modifications.

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Produced by:
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91072 Herzogenaurach (Germany)
Postal address:
Industriestraße 1–3
91074 Herzogenaurach (Germany)
www.ina.com

Printed in Germany by
frankendruck gmbh, 90025 Nürnberg

Testing: Cam Phaser Systems

The ever shorter product development times of car manufacturers require ever faster and more effective product development. An elementary component of product development is the validation of new products by testing. These tests are necessary in order to ensure the function and durability of such products, secure new production methods, guarantee uniform product quality and enable the continuous further development of the products.

Different testing methods are employed, according to the complexity of the products to be developed.

An example of a product made up of several subsystems is a cam phaser system. This system is comprised of a cam phaser unit, proportional valve, sensor technology, accessory parts and a control unit. For this product, INA makes the cam phaser unit, proportional valve and accessory parts available to its customers. The function of this system depends on the complex interaction of mechanical, hydraulic, and electrical components.

The functionality and durability are tested for the complete system, as well as for the separate components.

For verification, the need for modern, largely self-developed test rigs are absolutely essential. At the present time, the testing of cam phaser systems from the first prototypes right up to the later mass-produced parts is being conducted on more than 20 test rigs, on which more than 100 different tests can be performed. In addition, the relevant application control units are also necessary in order to optimally match the functional characteristics of the cam phaser system, such as phaser shifting velocity, control accuracy and oscillatory behavior, to the respective combustion engine. This ensures that the customer will later achieve optimal fuel savings, reduced emissions and enhanced performance and torque.

The Design Verification Plan (DVP), which defines the tests for the different prototypes phases right up to production parts, serves as the guiding document for the entire testing phase. The test methods and test rig technologies described in this brochure are utilized during this testing phase. Examples of measurement results are presented in this brochure.

Testing Methods

For the planning, development and release of new product concepts or new applications for already existing concepts, a wide variety of testing methods are employed during different stages of the product development process.

The following test methods are some of the examples used:

- Component Functionality Testing
- Component Durability Testing
- System Functionality Testing
- System Durability Testing.

These test methods are briefly described in the following sections.

Contents

Component Functionality Testing

Cam Phaser Testing according to Engineering Specifications

Engineering specification testing serves to check the functionality of the cam phaser outside the combustion engine (series and development). Measurement results obtained using the component test rigs are then compared with those values found in the given specification.

For the different tests performed, the rotor unit of the cam phaser is mounted to a test rig adapter. This simulates the mounting geometry and the oil supply of the camshaft.

The stator unit is connected to a drive, which can shift the phaser or hold it in a fixed angular position.

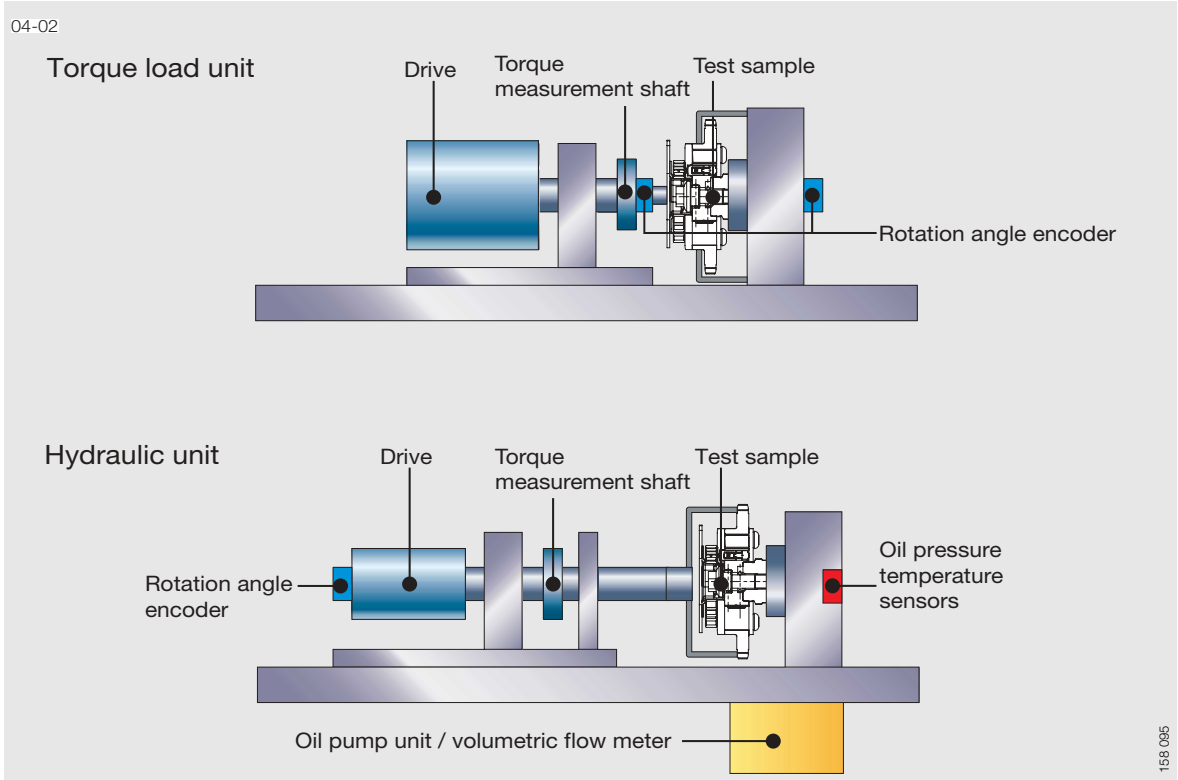
For testing, a component-compatible test oil is used, in which its properties simulate those of engine oil. The temperature and pressure of the test oil are according to the specification.

Test Rig

04-01

Measurement Setup

04-02



Component Functionality Testing

Cam Phaser Testing according to Engineering Specifications

The following parameters are measured:

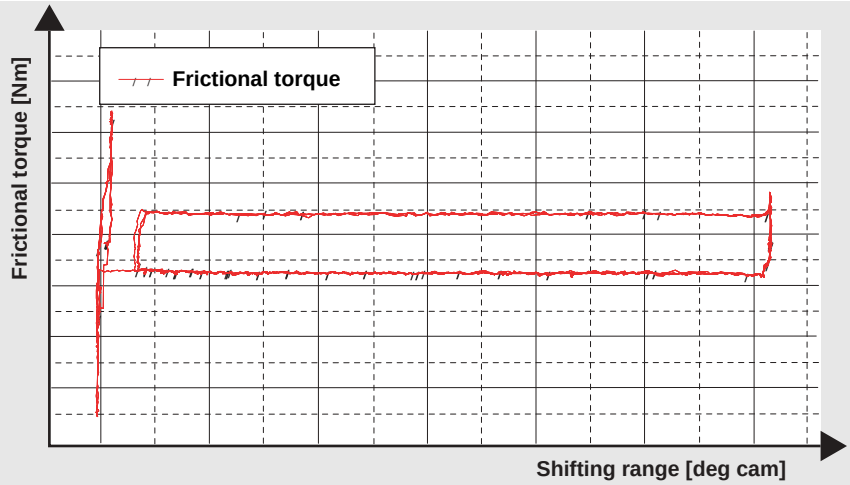
- Oil pressures
- Air pressures
- Oil temperatures
- Phase angles
- Oil volumetric flows
- Torque.

The following characteristics are determined from the values measured:

- Cam phaser internal leakage between the chambers
- Cam phaser external oil leakage
- Cam phaser external air leakage
- Shifting Range
- Frictional and spring torque over the entire shifting range
- Locking clearance of the mechanical locking mechanism
- Mounting Bolt Torque.

Friction/Shifting Range

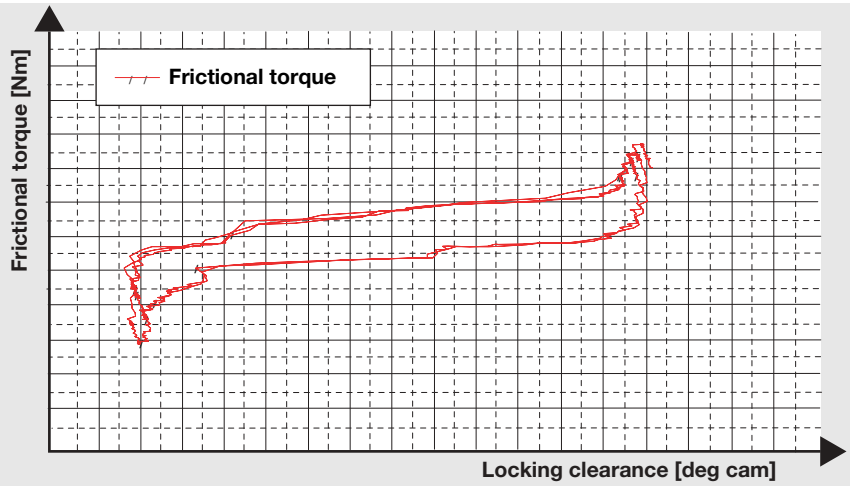
06-01



158 096

Locking Clearance/Zoom

06-02



158 097

Leakage Measurement

06-03

Position	Base	Middle		End
Pressure direction	Advanced	Advanced	Adv./Ret.	Retarded	Retarded
Oil temp. / ˚C	32.80	32.80	32.90	33.00	33.10
Test pressure A / bar	–0.01	–0.01	4.00	4.01	4.00
Test pressure B / bar	4.01	4.02	4.01	–0.01	0.00
Angle / ˚	0.02	12.98	13.03	13.00	26.02
Leckage $\dot{V}$ / l/min	0.33	0.39	0.08	0.38	0.37
Differential Pressure / bar	4.00	4.01	0.01	4.00	4.00

158 098

Component Functionality Testing

Proportional Valve Testing according to Engineering Specifications

The measurement of the electrical properties, magnetic force vs. stroke and oil flow vs. current characteristics serves to check the functionality of the proportional valves and switching valves of the individual components (series and development). The measurements are performed on the test rig and the results are compared with the values found in the given specification.

For the measurement of the magnetic force – stroke characteristics, the valve is installed on the magnetic measuring rig without its hydraulic component and the force vs. stroke characteristics are measured for constant magnet current supply.

For the measurement of the oil flow/current characteristics the proportional valve or the switching valve is installed in a test rig adapter block. This is to simulate the geometry and oil supply in the combustion engine.

For testing, a component-compatible test oil is used in which its properties simulate those of engine oil. The temperature and pressure of the test oil is then adjusted according to specification.

The current is supplied to each test sample from a PWM power stage with recirculation or clamping diode, with a specified duty cycle.

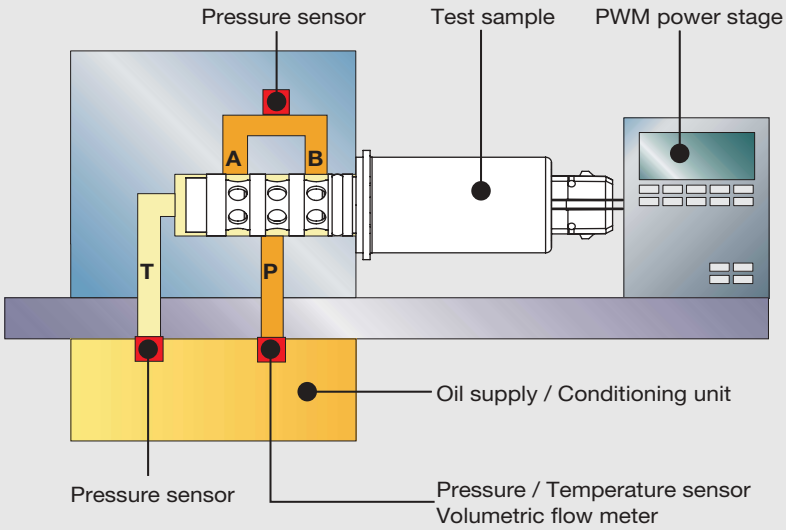
Test Rig

08-01

158 099

Measurement Setup

08-02



158 100

Proportional Valve Testing according to Engineering Specifications

The following parameters are measured:

- Electrical resistance
- Inductance
- Insulation resistance

- Magnet force
- Magnet stroke

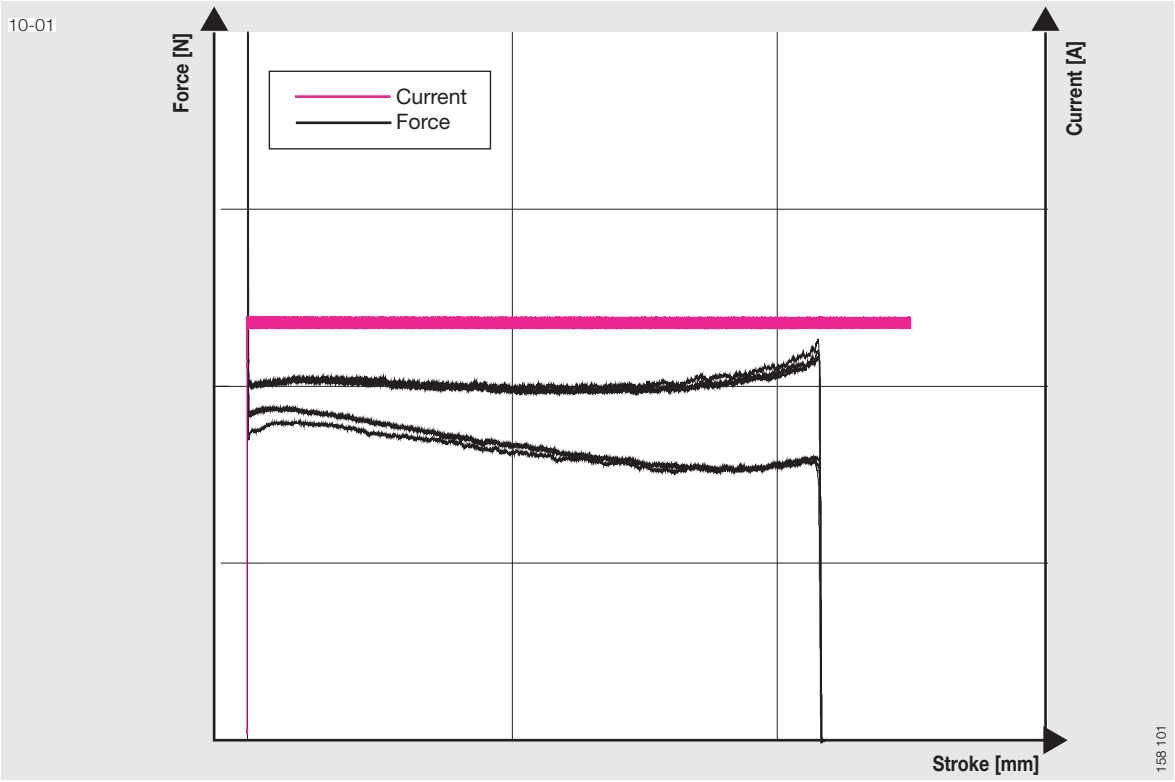
- Oil pressures
- Oil temperatures
- Oil flow rates
- Duty cycle
- Electrical current.

The following characteristics are determined from the measured parameters:

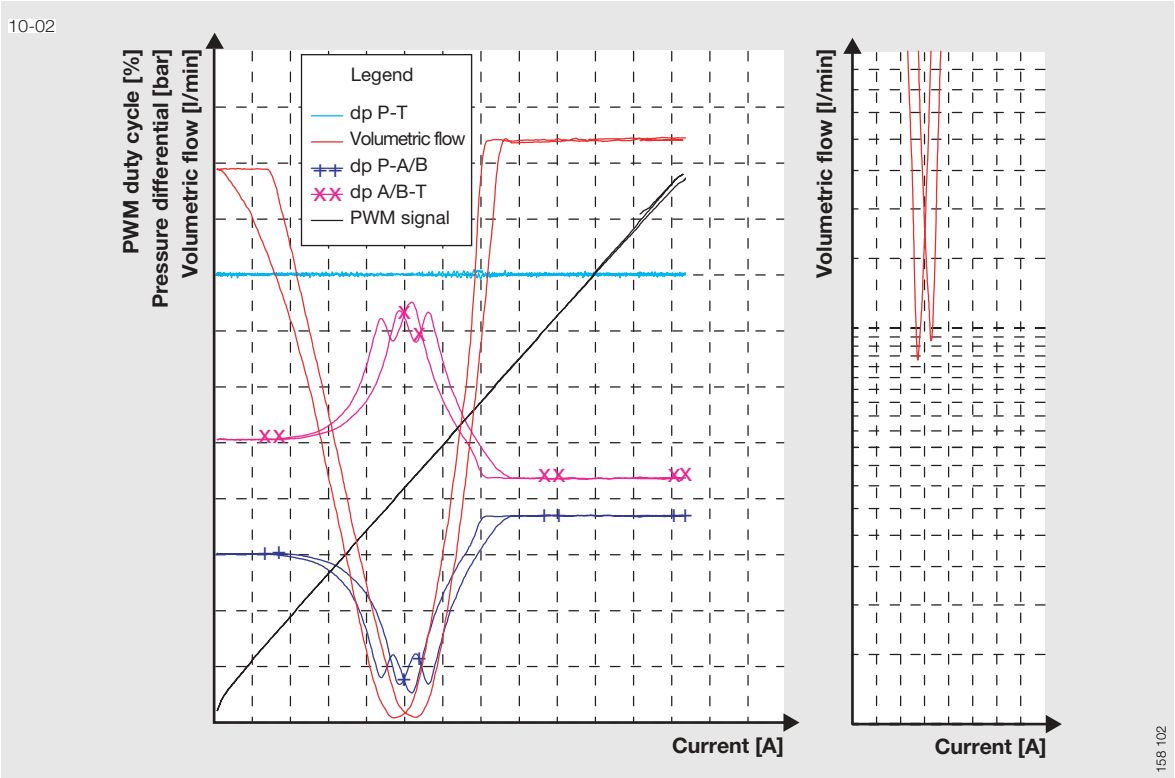
- Maximum magnet stroke
- Magnet force vs. magnet stroke for a given electrical current
- Magnetic force hysteresis

- Oil volumetric flow in the end positions
- Oil volumetric flow in closed position (leakage)
- Electrical current in closed position
- Hysteresis
- Pressure differences.

Measurement Results: Magnetic Force – Stroke Characteristics



Measurement Results: Oil Flow vs. Current Characteristics



Component Durability Testing

High-pressure Pulsation Test for the Components

This test serves to check and ensure the durability and sealing of cam phaser units, their components or proportional valves relative to oil pressure load in the combustion engine.

For this test the test samples are fastened to a test rig adapter. This simulates the mounting geometry and oil supply in the combustion engine.

It must be taken into account whether under real installation conditions if oil drainage is possible or if the system is sealed.

The dynamic oil pressure load is applied via an oil supply unit and a servo-valve, in which the controller regulates in accordance to the demand/actual oil pressures within the test sample. Here the actual pressures within the test sample are used as the controller input parameters.

Test Rig

12-01

Cam phaser

12-02

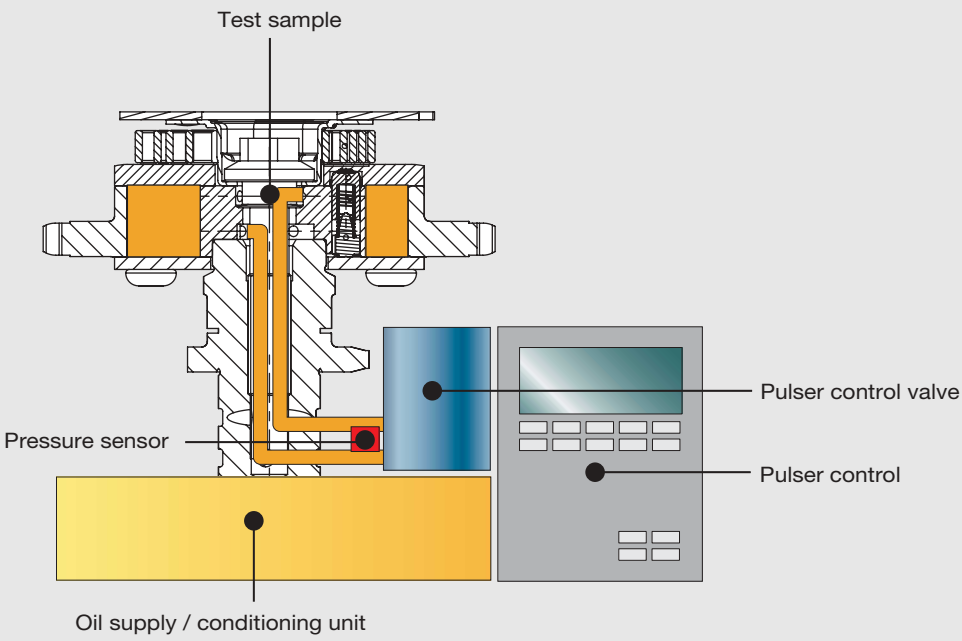
Proportional valve

12-04

158 103

Measurement Setup

12-03



158 104

High-pressure Pulsation Test for the Components

Pre-tests for cam phasers:

- Engineering specification tests
- Geometrical measurements.

Pre-tests for proportional valves:

- Engineering specification tests.

High-pressure pulsation test:

The dynamic, sinusoidal loading of the test sample or components is applied using oil pressure (ambient pressure up to 50 bar). The number of load cycles is individually defined (e.g. 10 million or 100 million cycles). The number of test samples depends on whether the testing is for basic research, development or production release purposes. The measured parameters are: oil pressure, temperature, loading frequency and number of load cycles.

Post-tests for cam phasers:

- Engineering specification tests
- Geometrical measurements
- Sealing test using static pressure loads
- Measurement of bolt removal torque.

Post-tests for proportional valves:

- Engineering specification tests.

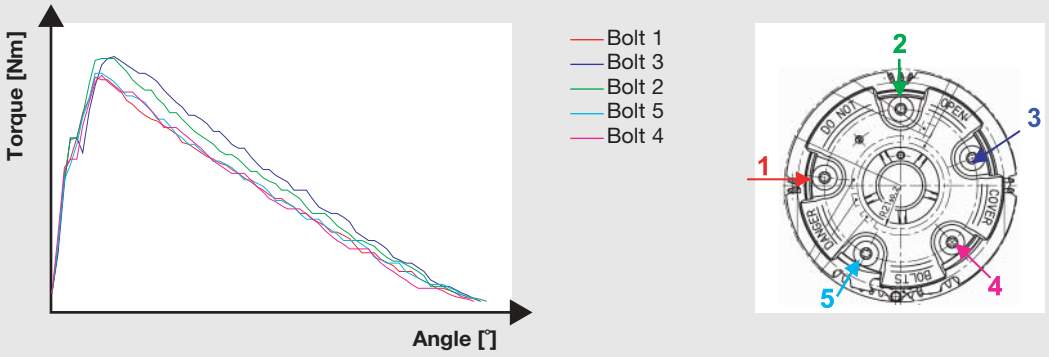
Evaluation:

Evaluation of the individual components with regard to wear and damage.

Documentation of the resulting damage (e.g. fractures with micrographs).

Bolt Removal Torque Tests

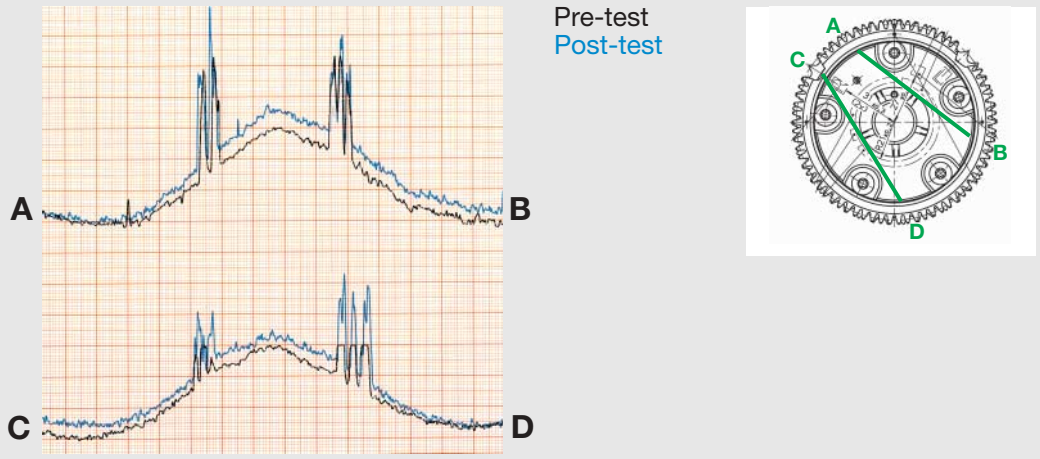
14-01



158 105

Geometrical Measurement – Example: Front Cover Deformation

14-02



158 106

Evaluation

14-05

14-04

158 107

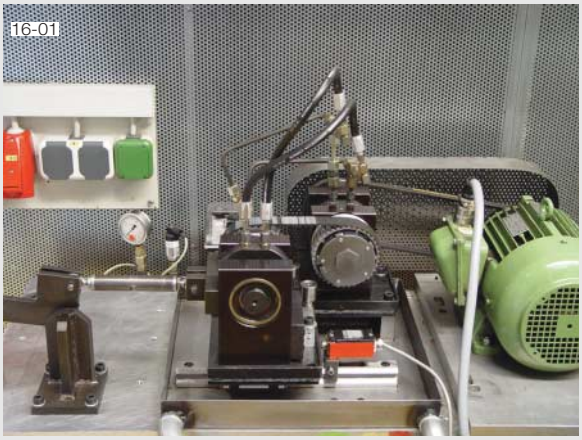
Dynamic Rotating Bending Fatigue Test for the Cam Phaser

This test serves to check and ensure the durability of cam phaser units with regard to rotating bending fatigue caused by the belt/chain drive.

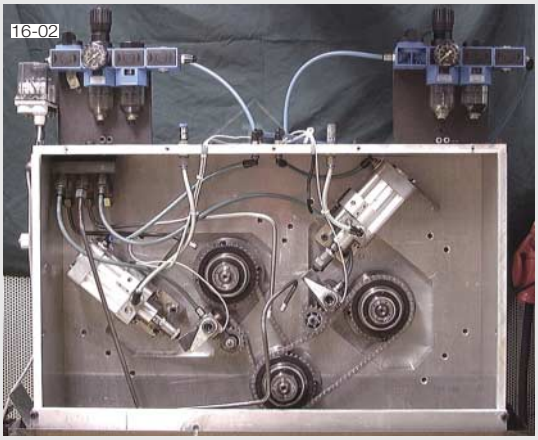
For this test the cam phaser units are fixed to each other with a belt or a chain and are rotationally loaded with the sum of the forces from the belt/chain drive, up to 10 million load cycles or failure. The oil supply for lubricating the units is introduced via the test shafts. The testing and verification of the durability is conducted at a constant load level with defined overload limit. The test can be performed for both belt or chain drive systems.

Test Rig

Belt drive

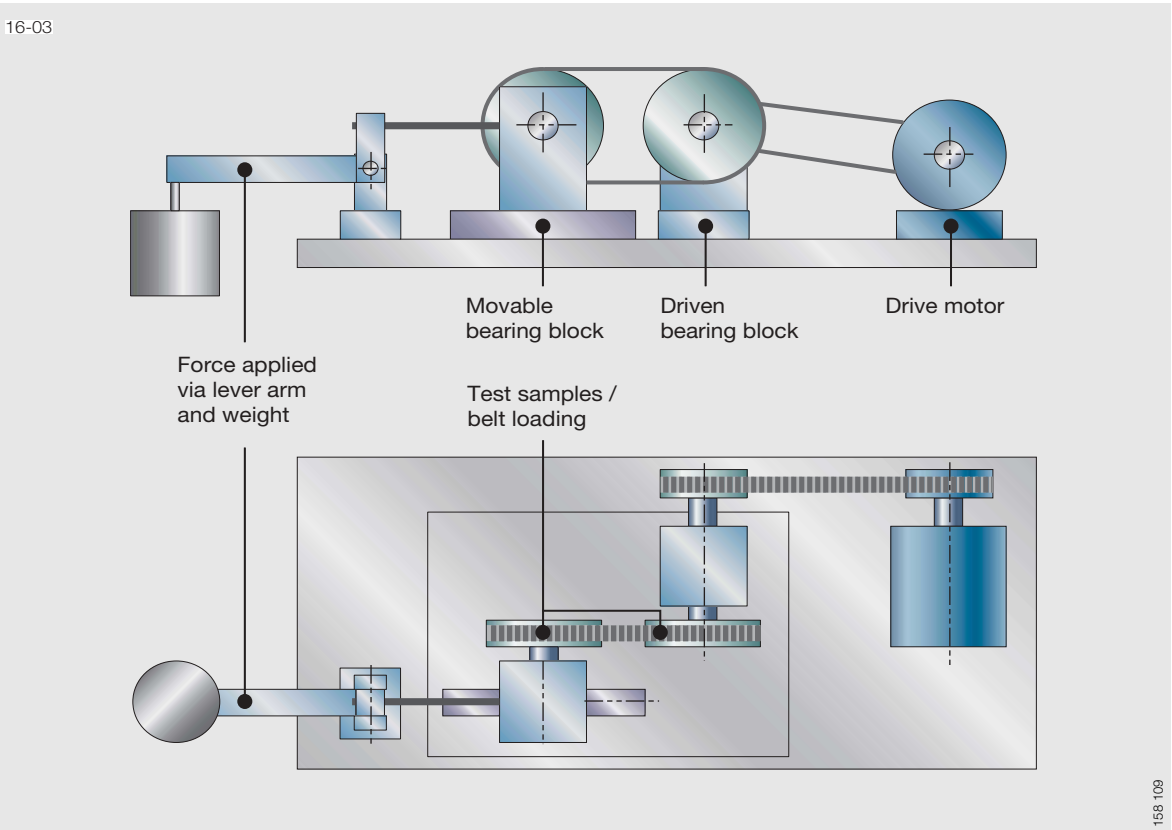


Chain drive



158 108

Measurement Setup (for Belt Drive)



158 109

Dynamic Rotating Bending Fatigue Test for the Cam Phaser

Pre-tests:

- Engineering specification tests of the cam phaser
- Geometrical measurements
- Run-out measurements between belt pulley/chain sprocket to rotor centerline or sealing ring contact surface.

Rotating bending fatigue test:

Cam phaser unit driven (two units per test) via belt/chain drive, loaded from the tensioned and slack side, without torque load (at present, possible wrap angle for belt 180°, for chain >180°), up to 10 million load cycles or failure. The parameters measured are: force and number of load cycles.

Post-tests:

- Engineering specification tests of the cam phaser
- Geometrical measurements
- Run-out measurements between belt pulley/chain sprocket to rotor centerline or sealing ring contact surface.
- Bolt removal torque measurements.

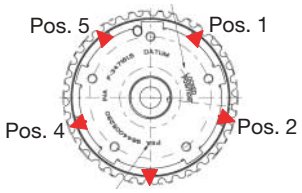
Evaluation:

Evaluation of the individual components with regard to wear and damage.

Geometrical Measurement – Example: Belt Driven Stator

18-01

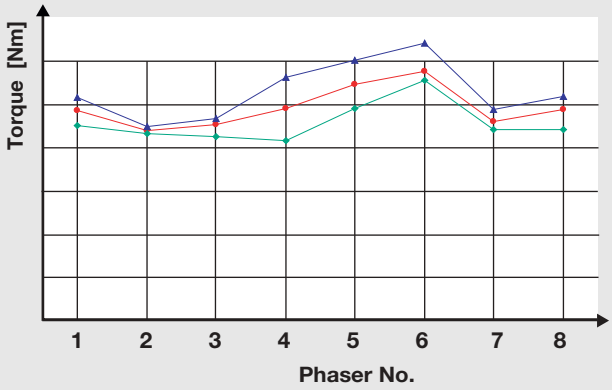
Belt pulley/stator		
Test 1	Pre-test x / mm	Post-test x / mm
Pos. 1	10.240	10.240
Pos. 2	10.265	10.265
Pos. 3	10.220	10.220
Pos. 4	10.175	10.175
Pos. 5	10.185	10.185

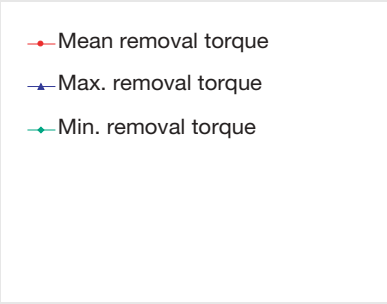


158 110

Bolt Removal Torque Measurements

18-02

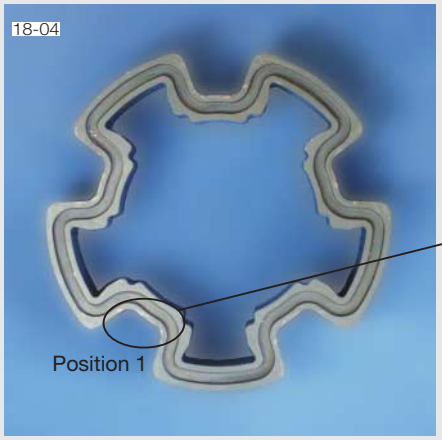




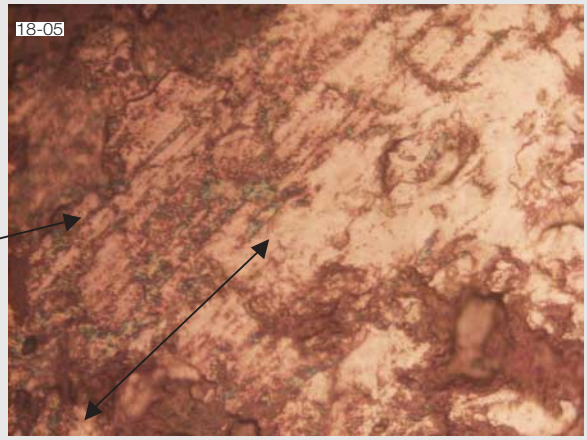
158 111

Evaluation – Example: Micro-Movement on Stator

18-04



18-05



Micro-movements in direction of arrow

158 112

Component Durability Testing

Durability Testing according to INA Specification and Environmental Simulation on the Proportional Valve

Durability tests must be conducted under realistic or stricter conditions that reflect customer requirements for their product's lifetime.

Solenoid valves are supplied with engine oil and electrically controlled under realistic conditions. The solenoids can be tested with oil temperatures ranging from +40 °C to +150 °C.

Ambient simulation tests must prove that products of this type satisfy a minimum stability against chemicals and temperature changes. This minimum stability guarantees the functionality of these products over their lifetime despite contact with chemicals and being subjected to temperature changes.

Solenoid valves are installed in adapter blocks and subjected to salt water, oil, gasoline, brake fluid and temperature shocks over a definite period of time.

Test Rig

Valve durability testing

20-01

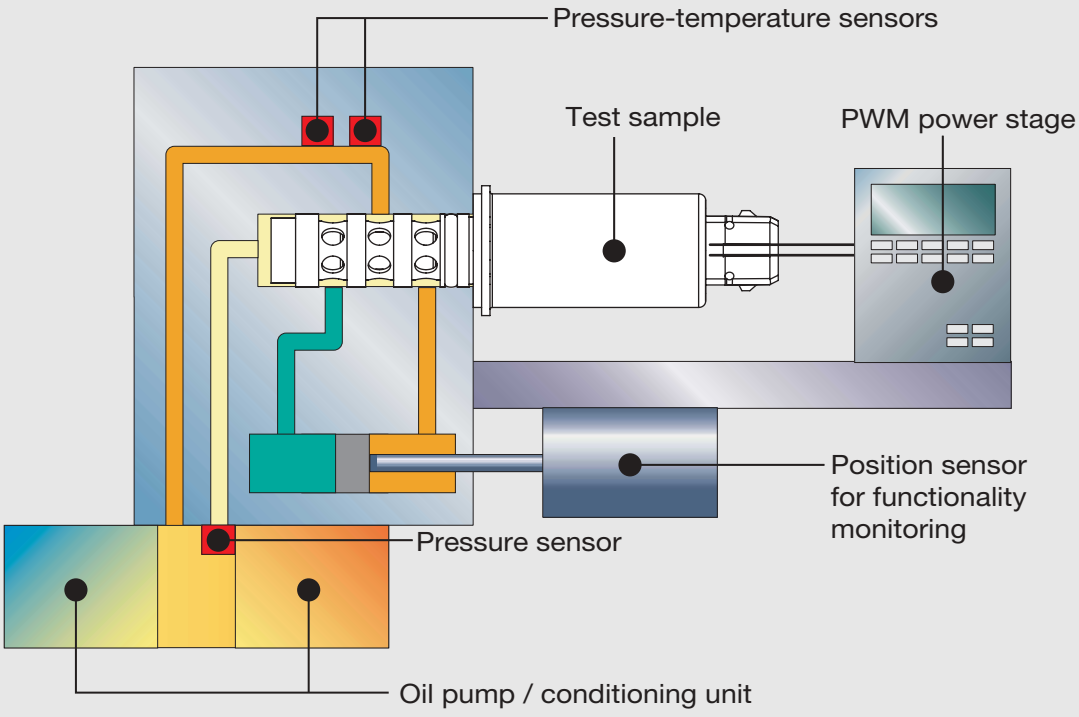
Temperature shock chamber

20-02

158 113

Measurement Setup for Valve Durability Testing

20-03



158 114

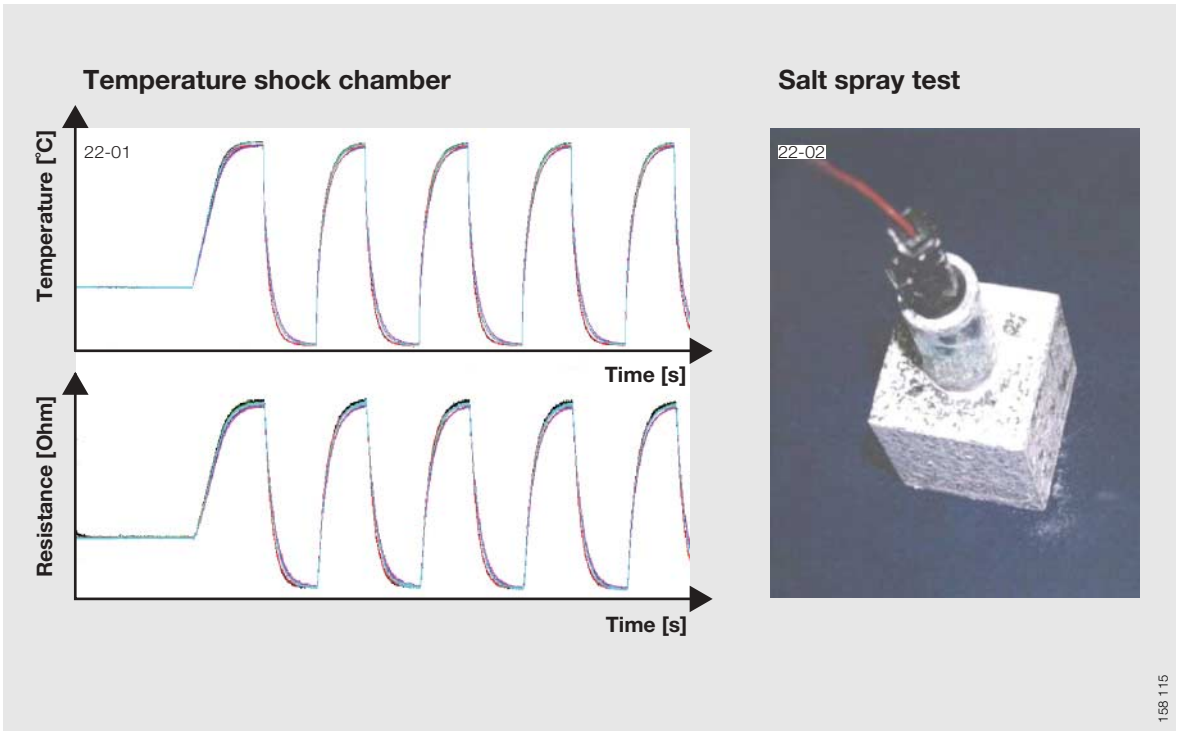
Durability Testing according to INA Specification and Environmental Simulation on the Proportional Valve

The following parameters are measured:

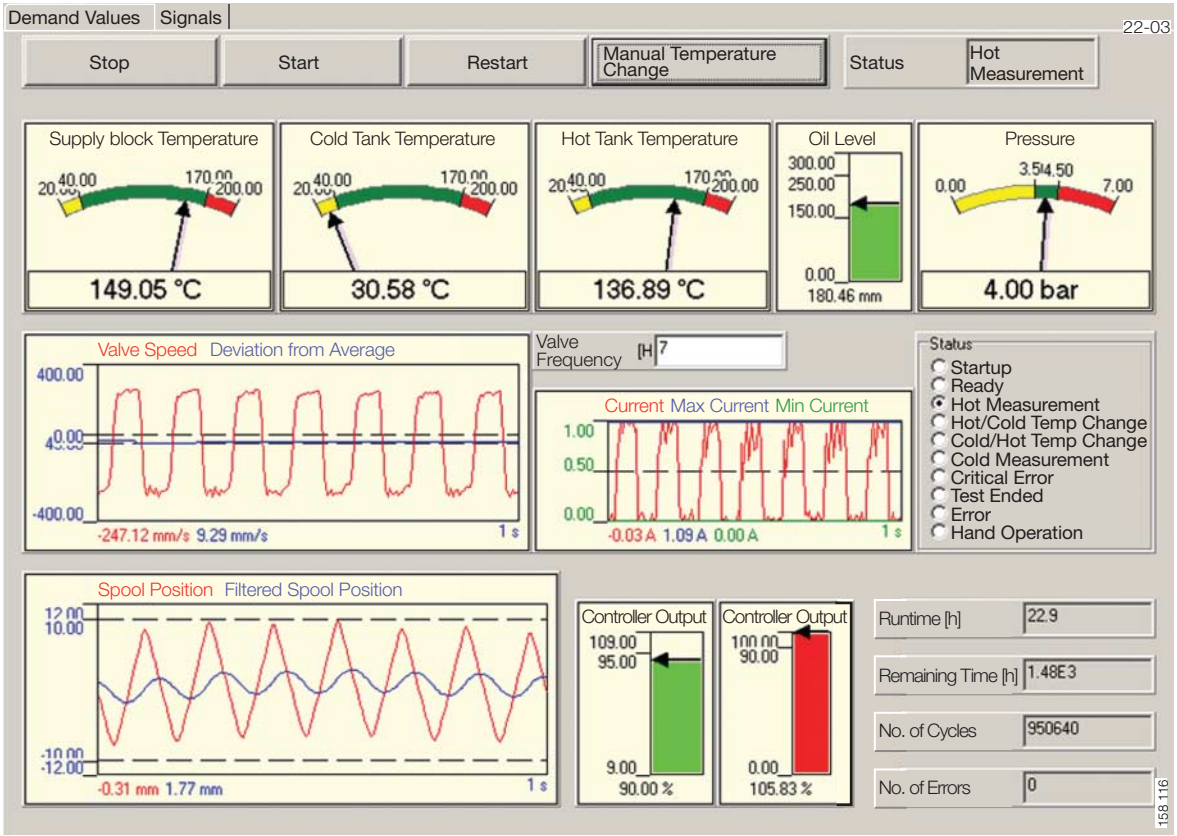
- Oil pressure
- Oil temperature
- Oil volumetric flow rate
- Duty cycle (PWM signal)
- PWM frequency
- Solenoid valve switching rate
- Solenoid valve switching current
- Magnet temperature
- Air temperature
- Duration of test.

Before and after the tests, functional measurements are performed and the amount of wear evaluated.

Measured Result



Durability Test Monitoring



System Functionality Testing

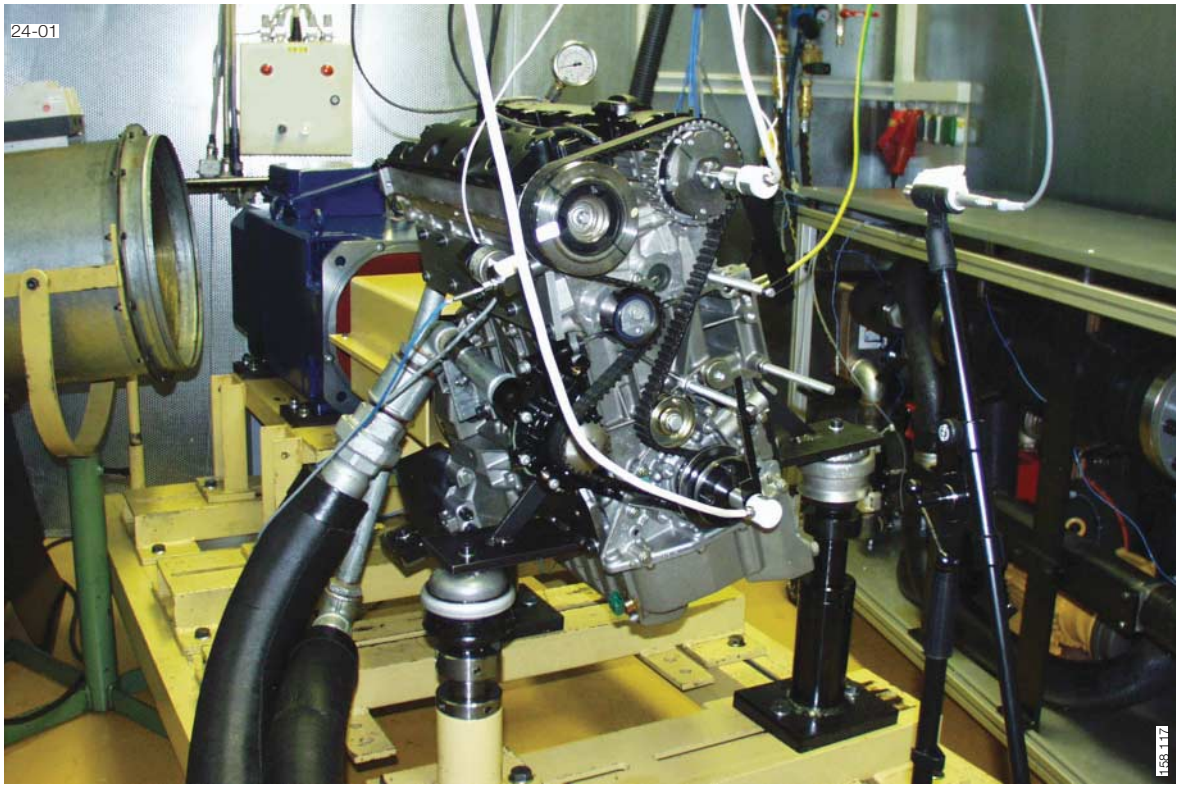
Motored Engine Function Tests

This test serves to evaluate the functionality of the cam phaser system on a motored engine (for development and series production phasers). The tests are carried out on the test rig and the results are compared with those found in the given specification.

For the different tests the cam phaser components are installed in the motored engine. The engine is then motored using an electric motor, via the crankshaft, and the engine temperature is externally controlled. The parameters are measured with the use of sensors on the shafts and in the oil channels. The cam phaser system is controlled by an universal control unit, which can be individually parameterized for any given test.

Test Rig

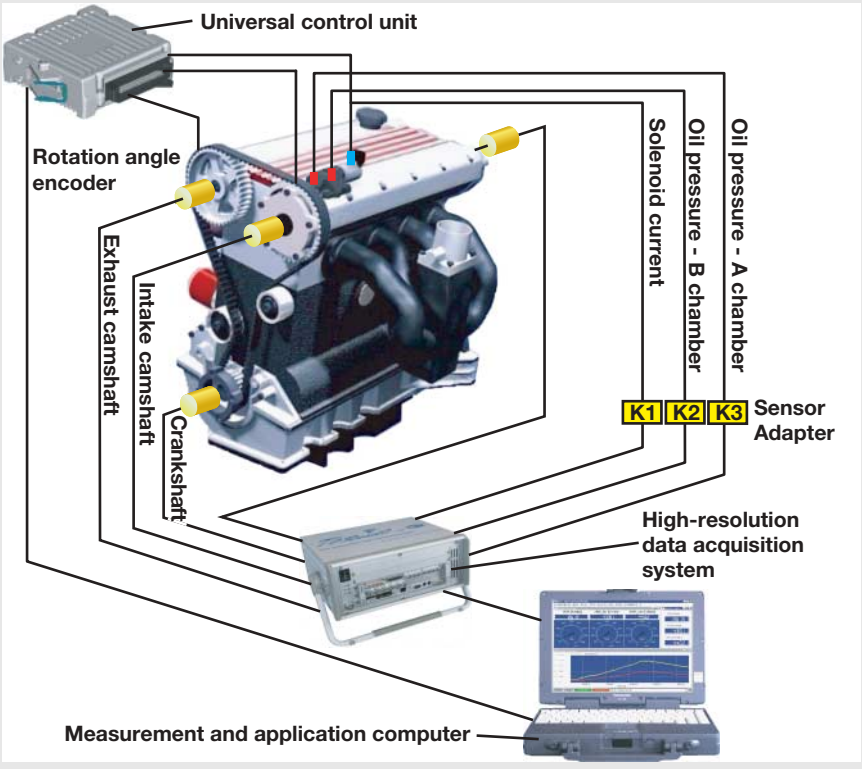
24-01



158 117

Measurement Setup

24-01



158 118

System Functionality Testing

Motored Engine Function Tests

The following parameters are measured:

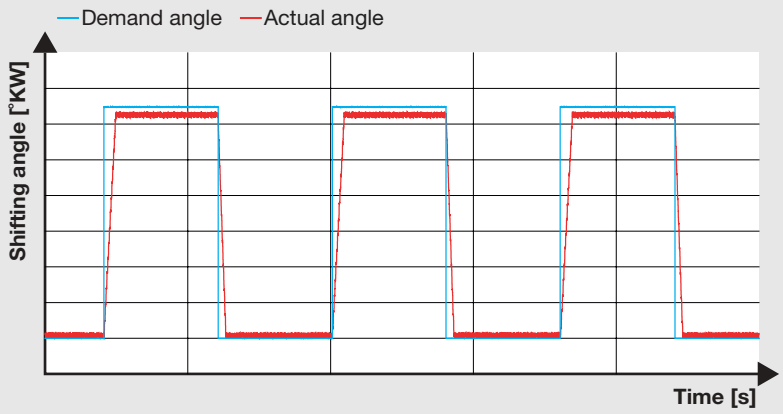
- Oil pressures
- Temperatures
- Rotational speeds
- CAN BUS data
- Solenoid currents.

The following characteristics are determined from the values measured:

- Shifting angle of the cam phaser
- Shifting velocity of the cam phaser
- Function of the locking/unlocking mechanism
- System control accuracy
- Cam phaser oscillation
- Oil pressures in the engine lubrication circuit
- Pressure oscillations in the cam phaser system.

Locking and Unlocking Capability of the Mechanical Locking System

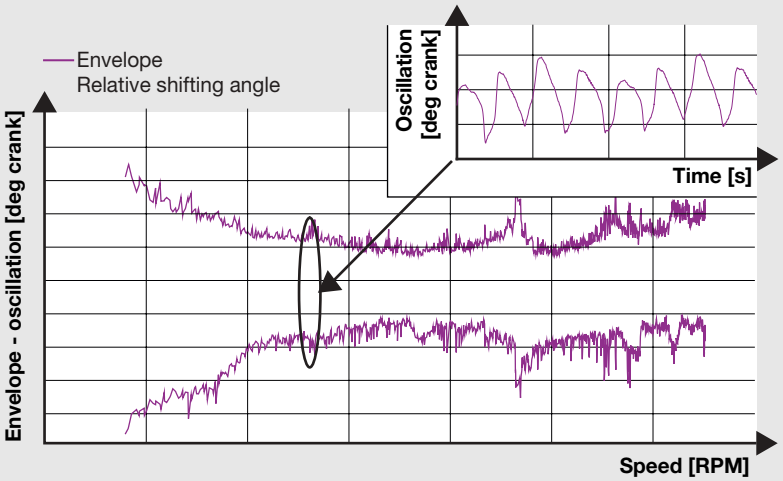
26-01



158 119

Camshaft Oscillation as a Function of Speed

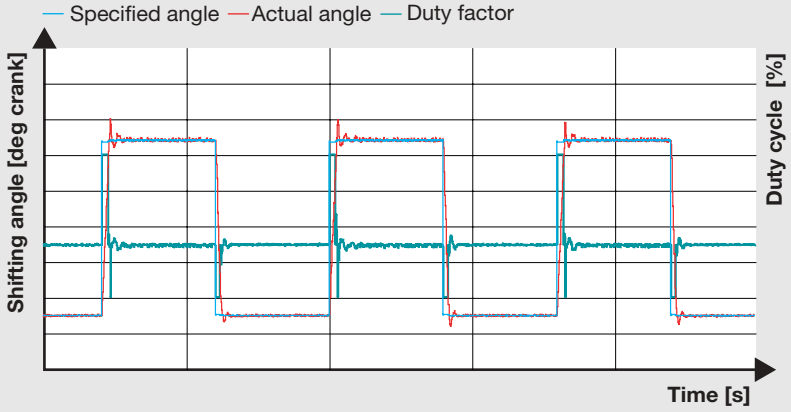
26-02



158 120

Control Accuracy of the Cam Phaser System

26-03



158 121

System Durability Testing

Motored Engine Durability Tests

This test serves to check the durability, functionality and wear behavior of cam phaser systems over the lifetime of the durability test.
Here, customer-relevant durability test cycles, resonance speed durability tests, permanent shifting durability tests (constant shifting of the cam phaser system) or constant timing durability tests (cam phaser systems constantly in controlled position), with run-times of up to 1200 hours, are carried out.

The cam phaser system may not show any signs of damage and wear restricting its function. These tests serve for the release of the cam phaser system in accordance with the Design Verification Plan (DVP).

For the durability tests, the components of the cam phaser system are installed in a fully motored engine. The engine is then motored using an electric motor, via the crankshaft, and the engine temperature is externally controlled. The durability test cycles are automatically performed by the durability test program. Before, during and after the durability test, functional tests are performed to check the functionality over the run-time. The components of the cam phaser system are then evaluated with respect to wear.

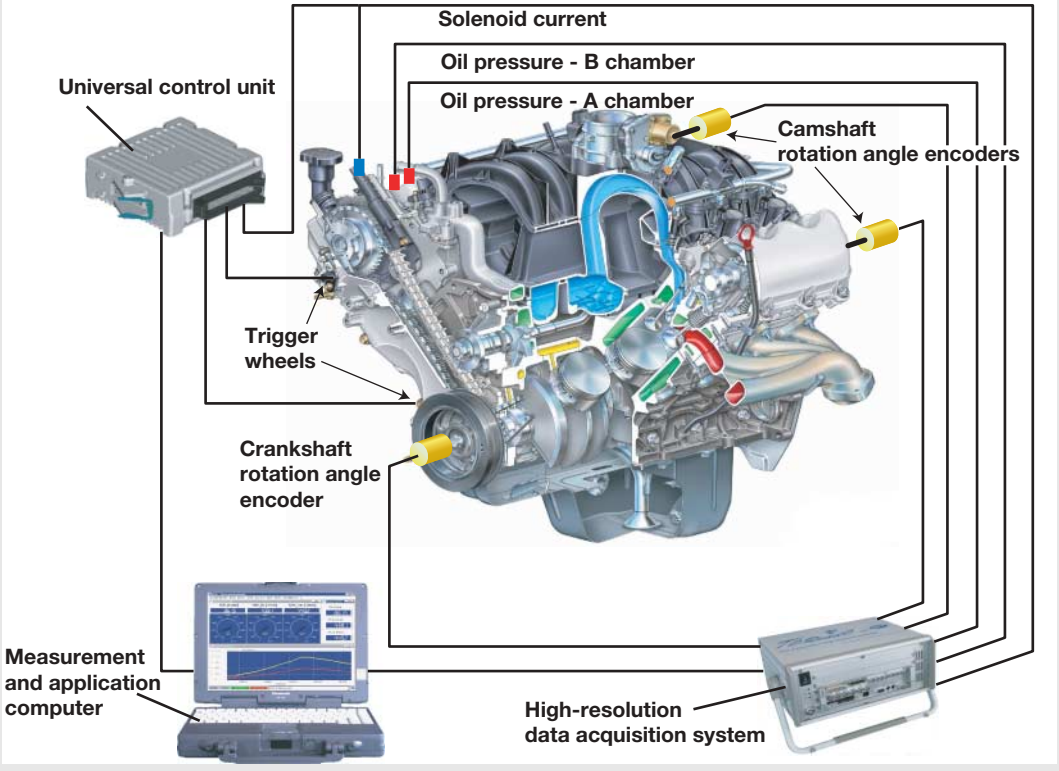
Test Rig

28-01

158 122

Measurement Setup

26-03



158 123

System Durability Testing

Motored Engine Durability Tests

The functionality is checked throughout the run-time by performing numerous function tests on the cam phaser system.

Pre-tests:

- Cam phaser tests according to engineering specification
- Proportional valve tests according to engineering specification
- Shifting velocity, locking/unlocking capability of the locking mechanism, control accuracy and oil pressure behavior at specific operating points.

Durability testing:

- Engine durability testing according to specification, with intermediate checks.

Post-tests:

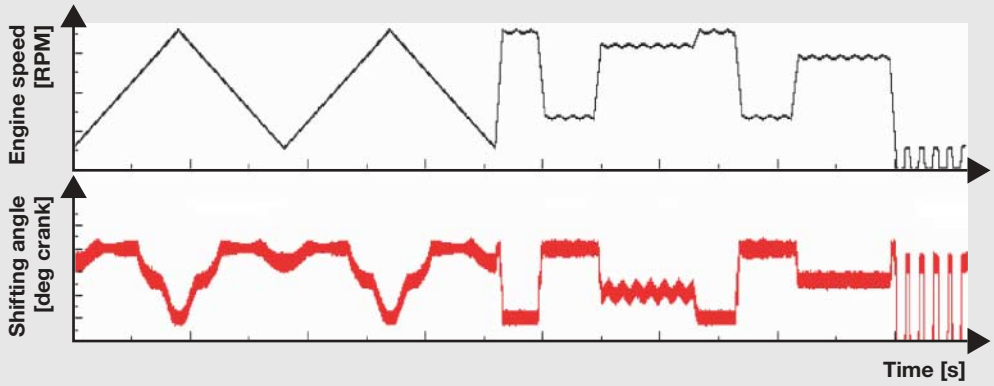
- Cam phaser tests according to engineering specification
- Proportional valve tests according to engineering specification
- Shifting velocity, locking/unlocking capability of the locking mechanism, control accuracy and oil pressure behavior at specific operating points
- Bolt removal torque.

Evaluation:

Evaluation of the individual components with regard to wear and damage.

Durability Testing Cycle

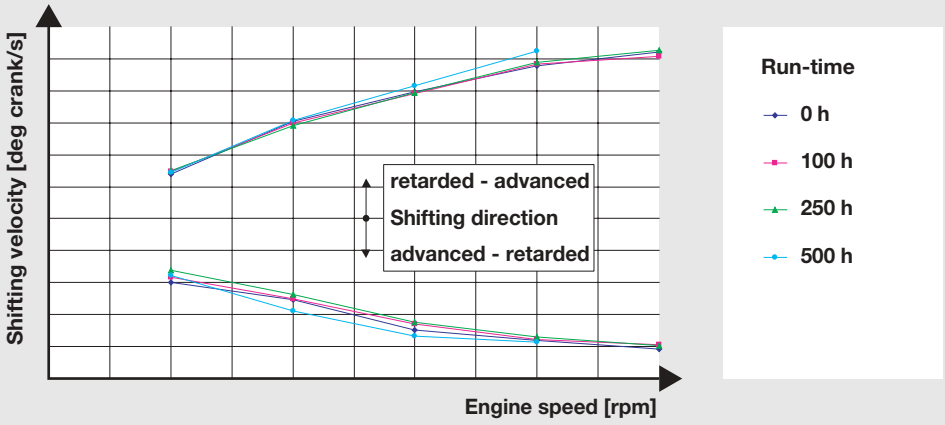
30-01



158 124

Function Test

30-02



158 125

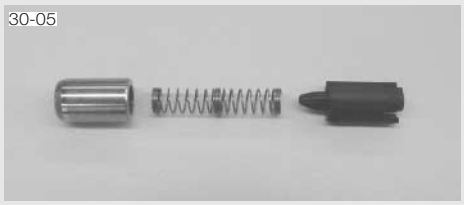
Evaluation

30-03

30-04

30-06

30-05



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