FOERSTER MECA-Probe Advanced Eddy Current Testing on Cams and Camshafts

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Abstract. Eddy current testing (ECT) is used as a standard production control in the automotive industry to detect cracks and pores on cams and camshafts.
Thereby, the test probes are scanning the profile of the cam by a mechanical "up and down" similar a valve motion on a camshaft.
This simple but very cost effective handling is limited in test capability to flat cam geometries and relative big defect sizes.
Increasing demands for cam testing based on sharper cam profiles as well as more critical defect specifications require new high sensitive eddy current test concepts based on a continuous perpendicular positioning of the probe element to the actual surface under test.

Therefore, the industrial development in cam testing was driven by the target to optimize the mechanical mismatching in angle in order to compensate disturbing effects.

High sophisticated NC-handling concepts documented the advanced possibilities in cam testing but the high cost of the mechanics as well as the reduced tact rates blocked drastically the industrial integration.

To overcome these specific problems and to offer a cost effective solution the company FOERSTER developed a special cam probe with integrated "smart mechanics"called MECA-Probe.
The concept guaranties up to 180 RPM that the probe element is always in a right angle to the surface of the cam. MECA-Probe offers a high sensitivity for cracks and pores, allows a high throughput and an easy integration into new or existing production lines.
Examples of industrial applications will document the advanced test potential.

1. Summary

In the field of testing rotation-symmetric components for defects, eddy current testing has established itself world-wide. Thereby, it has almost completely replaced alternative test methods such as magnetic particle inspection and dye penetration tests based on its high testing sensitivity, the high degree of automation it permits and the opportunity permits for documenting the measurement results.

In contrast to the above, eddy current methods are to be found in use only very rarely in industrial series production situations where complex test geometries have to be tested. The principal reason for this is the interference resulting from the geometry of the component which is superimposed on the measurement signal and which significantly limits the finding of defects.

Now the MECA-Probe opens up for the first time a simple and cost-optimized test method that is also suitable for components with complex geometries. This is achieved through the combination of mechanical components integrated in the probe and sensors executed in a targeted manner. Taking the example of testing camshafts with a "sharp" cam geometry, the basic principle of the conceptual solution will be presented in respect of its potential for use in industrial applications.

2. Introduction

The eddy current testing method is used world-wide for testing surfaces for defects (cracks and pores open on the surface). It permits high testing speeds and high throughputs. In this way it is suitable in particular for use in production-accompanying 100 % testing cycles. In addition the method does not require any consumable materials or coupling media. Comparison with the (consumption-material and personnel intensive) test methods used to date makes clear that the higher investment costs of an automated eddy current solution are more than compensated for by the significantly lower operating costs. This leads to significantly lower operating costs for the testing of each component in series production. (Fig. 1).

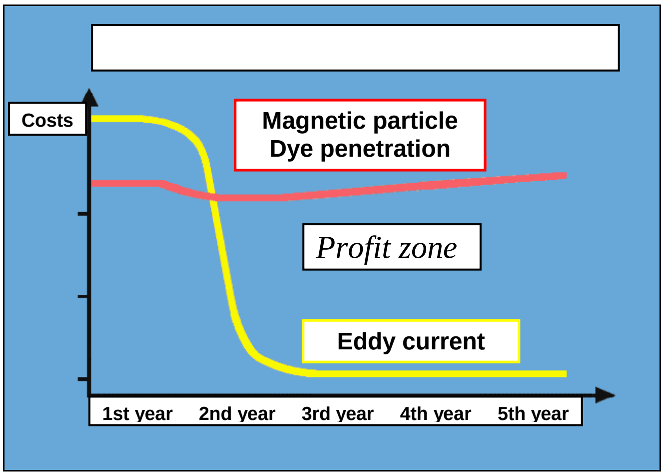

Fig. 1: Cost comparison for the use of the eddy current method in relation to the magnetic particle inspection and dye penetration methods.

Whereas cylindrical parts which have to be tested offer optimum conditions in respect of the test sensitivity and also in respect of the mechanical handling of the component the use of the eddy current method on components with more complex geometries is limited as a result of the superimposed interference effects resulting from the particular geometry of the component. Approaches aimed at making such testing tasks accessible for the eddy current technique have led either to expensive and time-consuming evaluations of the signals or, as the case may be, to testing solutions involving NC controlled guidance of the probe. In many cases of application these lead to the given cost framework being exceeded as a result of the time-consuming handling necessary. As a result the eddy current testing method has been excluded from these applications up to the present time in spite of its high testing potential and its objective evaluation of the measurement signals.

3. Principle of the eddy current testing method

The high-frequency application of the eddy current testing method with so-called differential probes (Fig. 2) allows the detection of surface defects. In this way very small, local inhomogenities (cracks, pores etc.) on the component surface can be detected with high sensitivity.

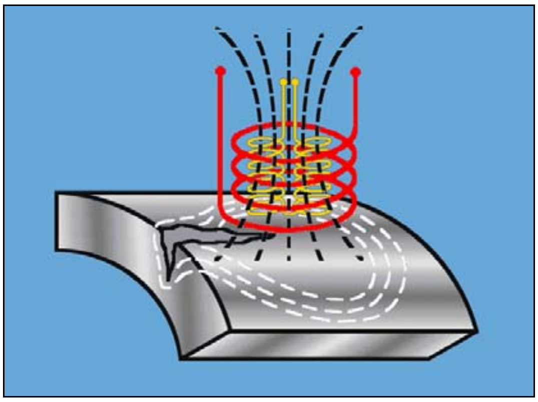

Fig. 2:
Principle of an eddy current probe for the detection of surface defects.

Fig. 3:
Typical eddy current probes for the detection of surface defects.

A wide range of probes (in respect of size and coil characteristic values, e.g. effective track width of the probes) is an essential precondition to match the method to the particular task of the customer, Fig. 3.

4. The Influence of the test-part geometry on the detection of cracks

With the eddy current method, maximum testing sensitivity is only obtained when the probe is kept at right angle to the workpiece surface as it is moved over this during the test sequence. If, in the testing of a cam, only height or stroke compensating of the probe is carried out (and not angular matching), every variance of the test-part geometry from a rotation-symmetric shape will lead to a significant interference factor.
Fig. 4 shows - by way of example of the detection of a 0.3 mm deep, artificial crack - the increasing interferences resulting from differences in test-part geometry.
Whereas the crack in a test-part with the "ideal" geometry (Fig. 4a) is detected with a very high signal-to-noise ratio testing of the "flat cam geometry" (Fig. 4b) makes clear the reduction in test sensitivity through the geometric interference factors. Only the use of the clearance compensation (internally in the eddy current system, see the clearance curve in the lower half of the graph) makes it possible to detect the artificial crack. With "sharp" cams (Fig. 4c) the geometry effects are so significant that the interfering signals overlay the crack signal located in the middle of the two interfering signals.

Accordingly with the current "status quo" of eddy current testing (i.e. with simple stroke compensation) "sharp" cam geometries have to be regarded as being not able to be tested.

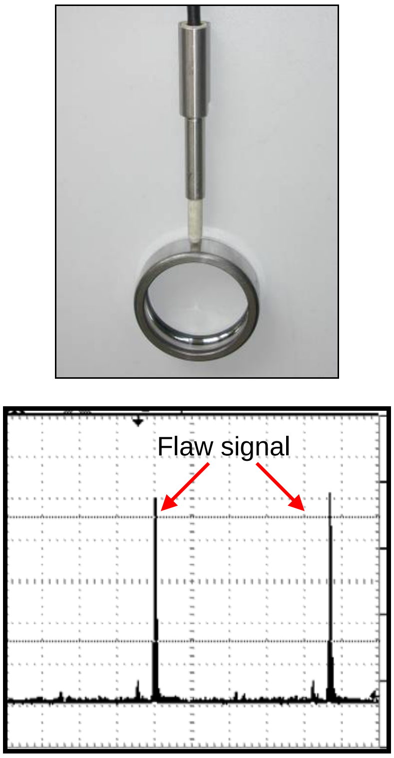

Fig. 4a:
No geometry influence with rotation-symmetric part

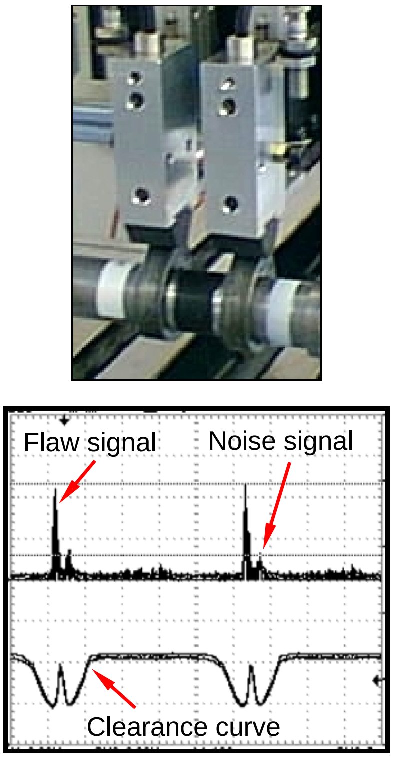

Fig. 4b:
Small geometry influence with flat cam

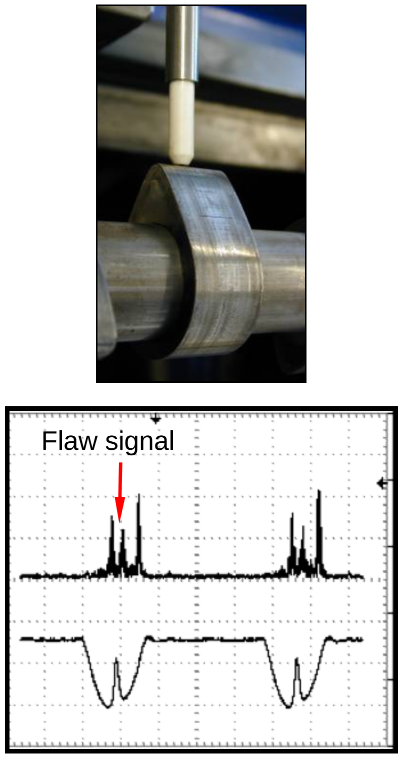

Fig. 4c:
Large geometry influence with sharp cam

5. Approaches for testing test-parts with complex geometries

The preceding section makes clear that for the testing of components with more complex geometries targeted angular compensation must always be carried out in addition to the stroke compensation in order to compensate for the geometric factors. For the application of the eddy current technique, this means that it must be ensured by means of targeted handling that the probe is always kept at right angles to the surface of the part to be tested as it is moved over the part. As solution approaches two basic concepts have been investigated intensively at FOERSTER's:

- Stroke and angle compensation with the aid of CNC-steered probe handling
- Stroke and angle compensation with the aid of a new probe concept with integrated mechanical setpoint tracking

The practical realisation of a CNC probe handling system made clear the limits of a universal mechanical handling system and of the currently available control concepts. Thus a handling concept was able to be realized that permitted exact setpoint tracking of the probe at right angles to the surface of the component. However measurements documented the fact that the maximum test speed that could be achieved was only approx. 60 rpm, this being a result of the high deflecting accelerations and the limited processing speeds of the CNC. This testing speed has - when account is taken of the necessity of testing a cam surface in a number of tracks - to be evaluated as inadequate for industrial application. At the same time the analyses showed that, although this concept permits flexible, non-contact testing to be achieved, the costs of doing this and the necessity to adjust the camshaft prior to the test mean that the method cannot be justified for industrial use.

Accordingly the approach of a mechanical setpoint tracking system integrated directly in the head of the probe was taken up and optimized in detail. Fig. 5 shows the new FOERSTER MECA-Probe concept, the probe having been optimized in a number of development stages. Based on a roller-guided setpoint tracking system, the probe element can be guided over and kept at right angles to the surface of the component even at speeds of 180 rpm.

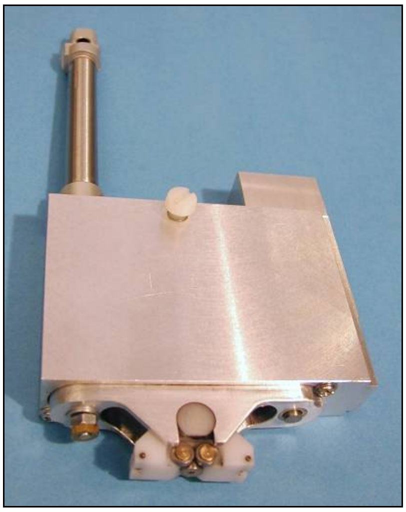

Fig. 5:
FOERSTER MECA-Probe

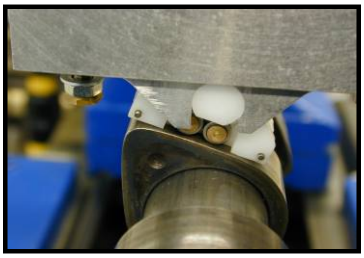

Fig. 5a: Alignment cam flank

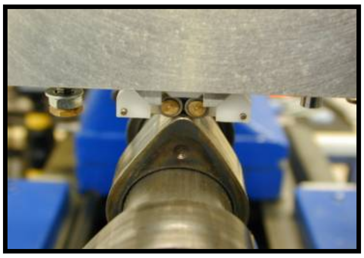

Fig. 5b: Alignment cam tip

A highly dynamic probe concept, which permits the sensitive detection of defects on components with complex geometries, was made possible through the use of weight-optimized individual modules as well as optimized probe elements. Fig. 6 documents the test potential realized in the detection of a 0.3 mm deep crack on a "sharp" cam geometry. Moreover, since the probe adjusts itself automatically when placed on the test-parts, the preliminary adjusting of the camshaft necessary with the CNC-steered handling system prior to the test cycle can be dispensed with. In this way the additionally required handling is reduced to just simple rotating of the camshaft and defined placing-on and lifting-off of the test sensors at the measuring process for all the camshaft types to be tested. Internal calculations have shown that by this means the overall expenditure for the mechanical components is reduced to 30 % of the costs of the CNC-steered solution.

Fig. 6a:
Crack detection with standard probe
(only stroke compensation)

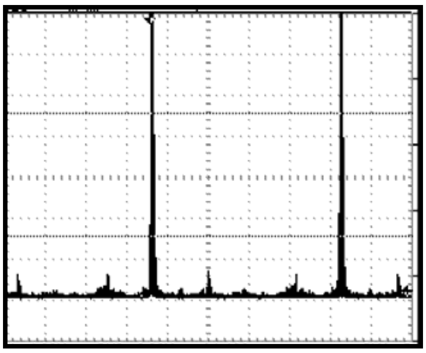

Fig. 6b:
Crack detection with MECA-Probe
(stroke and angle compensation)

6. Industrial applications in the testing of car and truck camshafts

The applications of the FOERSTER MECA-Probe document in impressive way the extended performance potential, the proof having been obtained with current industrial measuring tasks, which - according to the current state of the art - have been rated as unable to be carried out with eddy current testing.

6.1 Detection of hardness cracks

Fig. 7 documents the detection of a hardness crack (signal-to-noise ratio > 3) on a forged and hardened car camshaft.
Comparison of the signal of the defectfree cam ("noise") as well as the signal of the natural hardness crack on the cam tip with the signal of the artificial 0.3 mm deep sample crack (Fig. 7) show that the depth of the natural defect must be small. Investigations carried out by the customer confirmed that the MECA-Probe had reliably detected a crack with a depth of ≤ 0.10 mm.
On the basis of the positive results, the Asian car manufacturer has replaced the existing "classical" eddy current testing technique for camshafts with the MECA-Probe successively on four production lines.

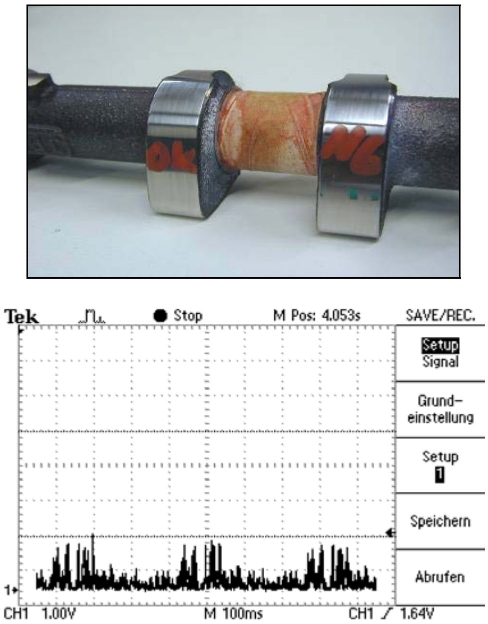

Fig. 7a: Crackfree cam

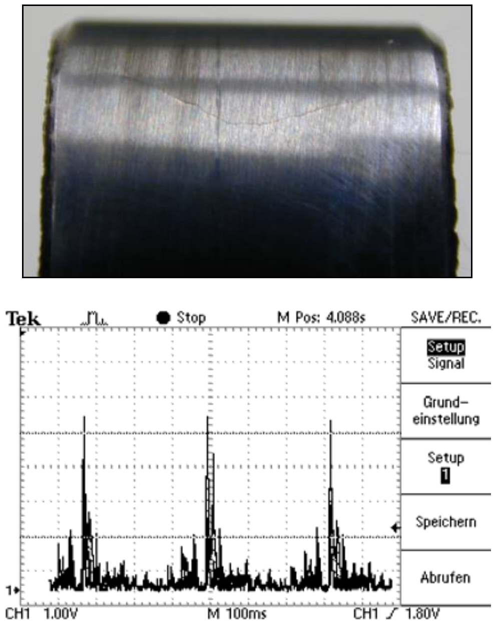

Fig. 7b: Hardness crack on the cam tip

6.2 Detection of grinding burn and grinding cracks

In addition to the detection of hardness cracks on car camshafts, the detection of grinding burn respectively grinding cracks represents a further goal for the extended opportunities for application of the MECA-Probe.
Fig. 8 documents results on a truck camshaft. Here different stages of burning damage on the surface of a cam were generated by defined variations to the grinding process. Investigations which were carried out with a conventional eddy current testing approach did not detect any damage.

In contrast thereto, the high test sensitivity of the FOERSTER MECA-Probe when "scanning" the surface of the asymmetrically shaped pump cam made possible not only the detection of the single crack but also the detection of the areally distributed fine network of cracks with a high signal-to-noise ratio and at a component speed of rotation of 180 rpm.

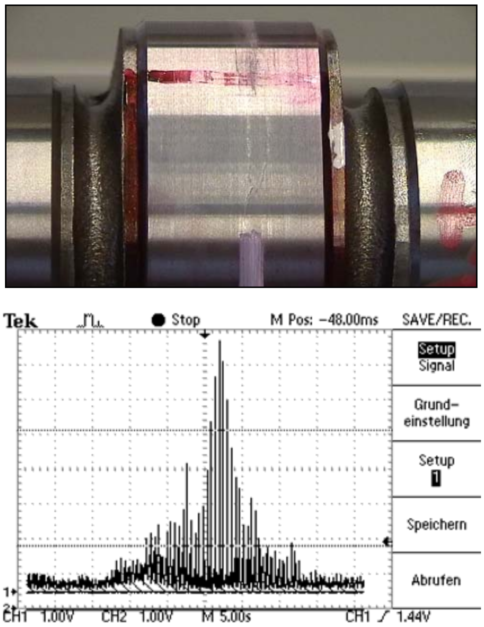

Fig. 8a: Single grinding crack

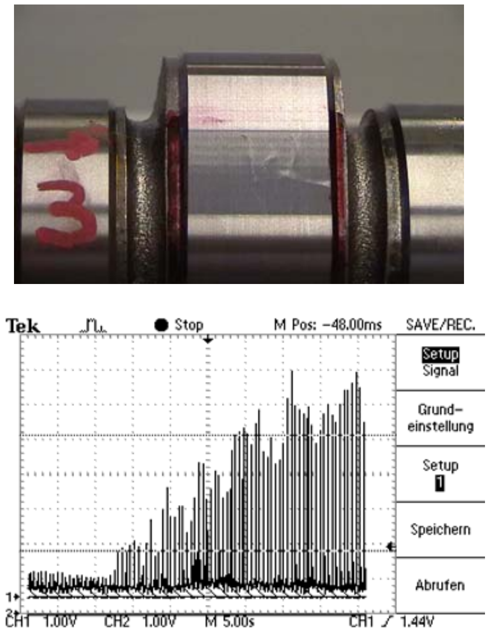

Fig. 8b: Network of burning cracks

7. FOERSTER single cam testing station

Based on the very promising application results, a standardized, modular concept was prepared at FOERSTER's not only for the testing of complete camshafts but also of single cams.

In co-operation with a handling partner which has specialized in the handling of cams and camshafts for many years, a powerful testing station (Fig. 9) was designed for the testing of single cams. The cycle time of these testing stations is 4 seconds / cam. Up to the present time a number of test lines have been successfully put into series production use.

This station contains all the elements of a modern cam testing system:

- Mechanical elements
  (feed, cam identification, master-test, sorting)
- Eddy current testing
  (testing for cracks and hardness of the cams)
- Additional components of a modern testing station
  (e.g. check on dimensions, remote-control, data documentation etc.)

Fig. 9: FOERSTER single cam testing station

The sequence of the test is made up as follows: After the cams have been singled, they are identified by a vision system (Fig. 10a). In addition, large shape defects in the cam tip (caused by a mismatching of the forging process) are detected. After this the cams are measured in respect of their geometry in a number of planes (Fig. 10b) in order to ensure that only cams with the correct dimensions are delivered.

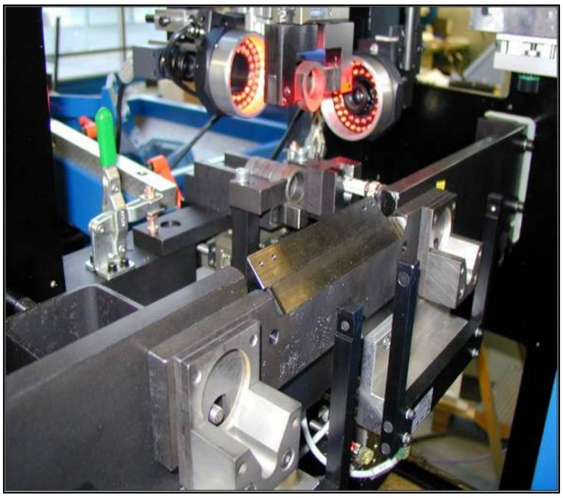

Fig. 10a: Vision system in the cam testing station

Fig. 10b: Test of geometry in the testing station

For the eddy current crack test of the cam surface and of its faces, each cam is clamped on a clamping mandrel (Fig. 11a) and - while being rotated - is tested by two MECA-Probes and two angled standard probes (Fig. 11b). In the next process an eddy current crack test of the inside hole is carried out. For this a rapidly rotating probe is moved into the cam hole (Fig. 12a) and the complete surface of the hole is scanned in helical sequence.

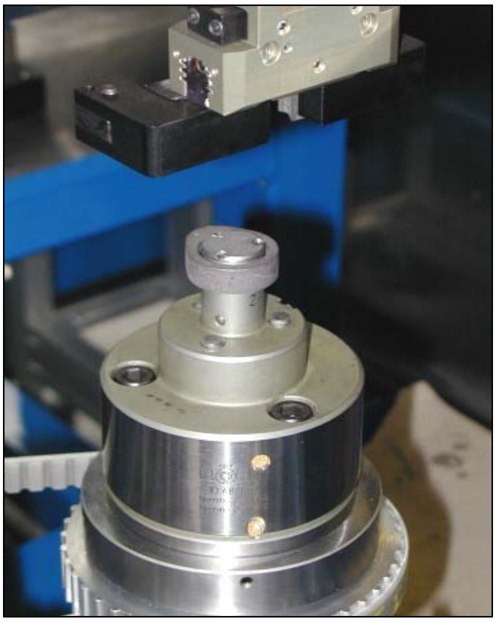

Fig. 11a: Cam on the clamping mandrel

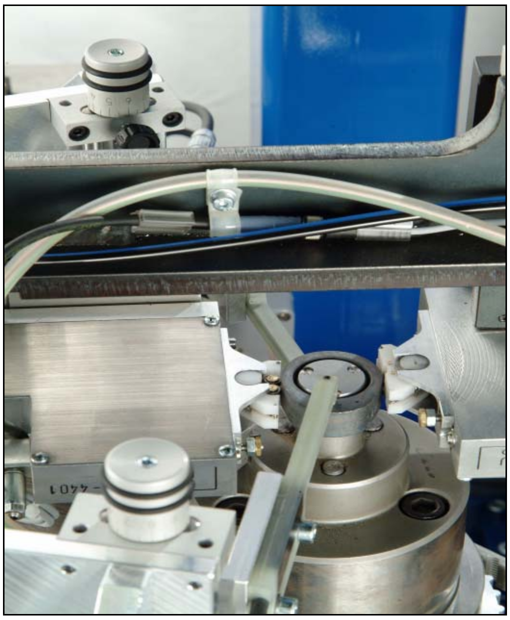

Fig. 11b: Eddy current crack test in four zones

In the final testing station the fact that each cam has received the correct heat treatment is checked by a magnet-inductive test with the FOERSTER MAGNATEST D. For this the cam is placed on plastic mandrel that can be moved vertically (Fig. 12b). For the test the unit with the cam placed on it is lowered into the FOERSTER MAGNATEST coil. After a multi-parameter check has been carried out by the FOERSTER MAGNATEST D, the cams are sorted as OK or NOK.

Fig. 12a: Eddy current testing within the cam bore hole

Fig. 12b: Hardness testing of a cam with FOERSTER MAGNATEST D

In summary, these overall testing concepts based around the FOERSTER MECA-Probe offer the end user the following advantages:

- **Cost-favourable end-to-end solution**
- **High test speed / throughput**
- **High test sensitivity**
- **Optimized handling**
- **Dimensional checks and remote service available as options**