KARL DEUTSCH

Crack Depth Measurement - Modern Measuring Technique for a Well-known Method

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1. Physical Basics of Crack Depth Measurement

At crack depth measurement due to the potential probe method, the electrical resistance between two points on the surface of a metallic workpiece is measured. When there is a crack between these two points, the electrical resistance is higher than in case of a crack-free surface. It is a measure for the requested depth of the crack. For practical measurement, a four-pole technique is used (fig. 1): Via two outside current poles S_1 and S_2, a constant current is passed into the workpiece. The voltage U (high-impedance) being measured between the other two poles M_1 and M_2 is proportional to the electrical resistance between them. Therefore, the voltage U depends, in a characteristical manner, upon the crack depth h, the known distances of the measurement poles 2a, the current poles 2s, and the electrical and magnetic properties of the material.

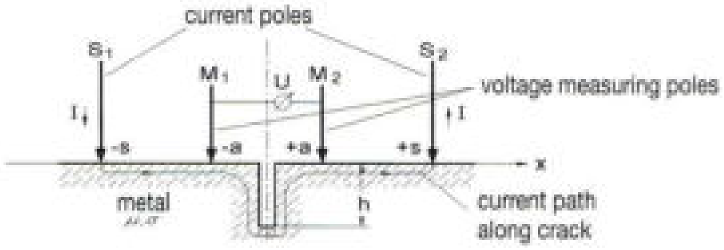


Fig. 1 Principle of crack depth measurement by the potential probe method

In case of alternating current, the electrical field resp. current lines are, caused by the skin effect, with growing frequency, displaced from the inside to regions just below the surface, where the current density is increased. The depth of penetration δ, where the current density is dropped for 63 %, can be calculated as follows:

$$\delta = \frac{1}{\sqrt{f \sigma \pi \mu \mu_0}} \qquad (1)$$

where
σ : spec. el. conductivity
μ : relative permeability
μ_0 : permeability constant
f : frequency

With increasing frequencies, the current more and more follows the contour of the surface, as shown in fig. 1 for the plotted current path. At the same time, similarly as in a wire with reduced cross-section, an increase of the resistance takes place. For direct current, i.e. without the skin effect, the current follows the path of lowest resistance, which approximately is equal to the geometrically shortest distance.

Therefore: For a precise crack depth gauging at low measuring currents, a.c. will be needed. The advantage: Burnt contacting spots on the surface of the workpiece and on the current poles are surely avoided. Furthermore, the current consumption in case of battery operation will drastically be reduced.

By the skin effect, the measured voltage on a crack-free place principally also is increased, and in addition, around a crack, by elongation of the effective current path. Only in case of a.c., a bigger distance of the current poles can be avoided.

Result: Smaller and more practicable probes with four integrated poles, higher resolution and accuracy. Even electrically better conducting materials, as high-grade steels or aluminium, can be measured, too.

2. Disadvantages of Conventional Instruments

Fig. 2 shows the interconnection of the crack depth h and the measured voltage U_d for a frequency of 3500 Hz. It is non-linear and, caused by different electrical and magnetic properties, different from material to material. This fact is only inadequately considered in conventional instruments.

As the measured voltages on the surface are extremely small (a few µV only), conventional instrument systems are very susceptible for interferences. Very often, the cable position influences the results of measurements, caused by induced voltages. In addition to this, uncontrolled contact problems occur, when the probe is attached on the surface. An abrasion of the probe tips can cause unforeseen scattering of the measured values. Measurements with hitherto existing three-pole probes and separate current pole are additionally erroneous, as the distance of the current pole is not defined.

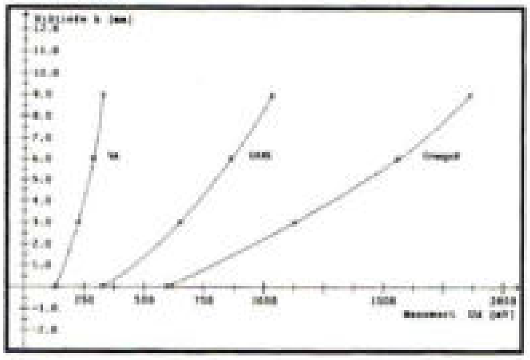


Fig. 2: Dependence of the measured voltage U_d on the crack depth h for different materials

3. New Probes for the Crack Depth Measurement

The new probes (fig.3) generally are equipped with four poles. Current- and measuring poles consist of spring-loaded, tip-hardened and gilded contact pins. They guarantee optimum electrical contact and require low attachment pressure only. The angled probe has, besides this, a prism-shaped attachment area; thus it causes that the contact pins are pressed on the surface by their spring-force only and almost equal during application. A misoperation is out of question. The prismatic shape of the attachment area also enables a safe positioning on cylindrically curved surfaces, e.g. pipes. By the angled shape, the probe head can also be positioned on inside surfaces of pipes or other hard-accessible workpiece areas.

Fig. 3: Crack depth probes:

with 90° measuring head right: with 0° measuring head

The straight-type probe has a square-shaped arrangement of the contact pins (fig. 4b) to be able to measure even on very small or strongly curved surfaces. In opposition to the linear pole configuration with the current poles outside (fig. 4a), the probe has to be attached in a manner that the crack to be measured is parallel to the marking on the probe tip, i.e. perpendicular to the connecting line of the measuring resp. current poles. The voltage drop, in this case, is measured a few millimetres beside the current path.

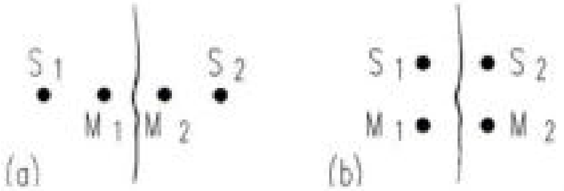


Fig. 4 Arrangement of measuring (M1, M2) and current poles (S1, S2)
a) linear arrangement b) square arrangement

The contact pins (fig. 5) can be exchanged without any tool: when worn, they can be pulled out of the guiding sleeve of the probe and new ones are pushed-in. The probes themselves never need to be replaced.

When the surfaces are scaled or oxidized, self-twisting contact pins are the optimum solution: They turn, when pressed against the surface, around their axes. A thin, non- or badly conducting layer thus will be punctured for a safe contact with the conductive background.

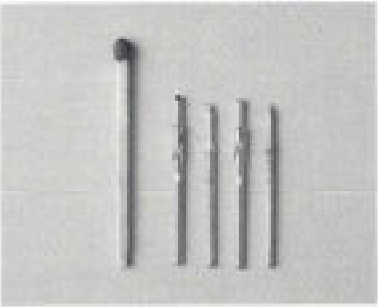


Fig. 5: Exchangeable and gilded contact pins

The built-in electronic circuitry (fig. 6) contains a preamplifier. Thus, the measured signal is safely handled to the evaluation and indication instrument. Furthernore, a storage element is also within the probe: Here, the individual probe data and material characteristics are stored.

Fig. 6: Integrated electronic circuitry: preamplifier and characteristics memory

4. The Measuring Technique

By means of the calibration bar contained in the delivery set, where an angular saw cut simulates an artificial crack of different depths, the user may check anytime, whether the probe still gives sufficiently exact measured values. Deviations caused by worn probe pins or extreme temperatures can be compensated by re-calibration. The corrected values are also stored in the probe.

The conversion of the measured voltages into crack depths takes place in the microprocessor of the instrument by comparison with the factory-set calibration tables. Prior to a measurement, the probe first is attached on a crack-free place of the workpiece. The voltage measured here is compared with the stored values of the characteristics memory. The individual characteristic for the material thus is automatically found and used by the microprocessor to determine the exact crack depth in the subsequent measurement.

The measurement itself is checked by the microprocessor for misoperation or inadequate contact by wrong attachment or shaking of the probe. False results, therefore, are nearly impossible. Result: Optimum reproducibility of the measurements (+/- 0.1 mm upto 100 mm crack depth) and low fluctuation. Even steel qualities of low or no permeability (e.g. Austenites) or non-ferrous metals of higher electrical conductivity (e.g. aluminium or brass), which show a tendency to higher inaccuracies, can be measured with sufficient precision.

5. The Instrument

The current through the workpiece is, similar to other conventional Instruments, 500 mA. But in difference to the existing technique, the current does not flow continuously as long as the probe is attached, but pulsed for a few milliseconds for one measurement. During "continuous" operation, approx. one measured value per second is formed and displayed. The battery-operated instrument, therefore, can "continuously" measure up to 12 hours with permanently attached probe. In case of rechargeable batteries, they do not need a dismounting, but can be recharged in the instrument by means of an external mains-charger unit.

The foil keyboard consists of a few key-in elements only, permitting a direct access to the basic measuring functions of the instrument. Further functions may be obtained via the menu key and given in clear text (English or German) on the display. The operation, therefore, is as simple and easy as of conventional wall or layer thickness gauges.

The data logger of the instrument can store up to 3850 measured values, which can be subdivided into up to 300 batches. A built-in real-time clock automatically records also the dates of a measurement series. Via an RS232-interface, the measurements can directly be printed out. The same interface permits a communication with a PC. For this purpose, the WINDOWS-PC program "STATUS WINDOWS" is available, which allows not only the transfer, but also the administration and graphic display of the measured values. Besides this, test reports and other kinds of documentation may be carried out.

6. Extended Functions - Measurement of inclined cracks

When cracks have an inclined direction to the surface, in most cases the inclination of the crack and its projection perpendicular to the surface is more interesting than the measured crack depth. The determination of the degree of inclination (angle α), principally is possible by a double measurement using a special probe. The recently developed execution is an angled four-pole probe (fig. 7) of the RMSL type with two outer current and two inside voltage poles which are functioning according to fig. 1, when the crack depth h is measured. The housing of the probe, however, is equipped with an additional socket to connect an external contact-magnet current pole. When the external current pole is connected, the non-marked outer current pole will be automatically switched off; thus, when the probe is attached to the surface, the current will flow between the contact magnet and the marked outer current pole. Furthermore, the frequency of the measuring current automatically is reduced to a value being optimally determined for inclined crack measurement.

The determination of inclined cracks is carried out by means of the external current pole and two measuring procedures (fig. 8). The second measurement is different from the first one by turning the entire arrangement of probe/external current pole for 180 degrees. In case of d.c., the current follows the shortest possible path s between the current poles. The current paths are, therefore, different in case of the two measurements A and B, causing different voltages at the voltage measuring poles. This effect also will be found in case of a.c., if the frequency is chosen to be so low, that the depth of penetration δ is still in the range of a few millimetres. The well-known advantages of the a.c. can be utilized also in this case. The difference of the measured voltages obtained between measurements A and B is a function of the angle α and show a typical behaviour for different groups of Material. The characteristic curve for the corresponding material is stored in a tabular form in the memory of the probe.

The value determined across the crack is automatically compared and normalized with a value obtained directly besides the crack. By this way, different distances between the external current pole and the probe are automatically compensated, so that the applicant is not always forced to spend his attention to this fact, except to maintain a certain minimum distance.

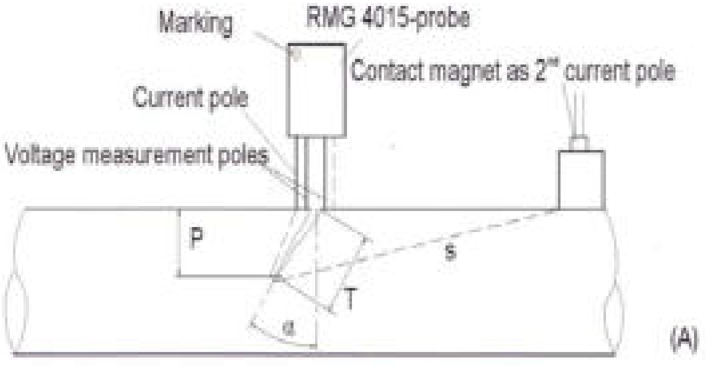
After carrying out measurements A and B, the instrument automatically shows the calculated angle α. An additional sign indicates the behaviour of the crack in relation to the position of the contact magnet (external current pole) during the last measurement: When the crack runs towards the contact magnet, the sign will be negative; runs the crack away from the magnet, the angle will be positively marked. When the plug of the external current pole is removed from the probe, the instrument is automatically switched over to the measuring mode with the higher frequency. Any crack depth now determined will internally be multiplied by the angle factor (cos α), and the interesting projections P of the crack depth is indicated in mm. This happens as long until the measuring function of the menu is deactivated resp. reactivated to measure the inclined direction of another crack.

Above 25°, the angle α can be evaluated in this way for all practicable materials with an accuracy of 10 % ± 5°. Only in case of crack depths below 2 mm or angles below 25° the measuring effect resp. accuracy will be lower due to physical reasons. The tolerances caused by small angles are unimportant in practice, as the difference of the actual crack depth and its projection perpendicular to the surface, below 25°, is maximum 10 % or less due to the flat behaviour of the cos α function around zero.

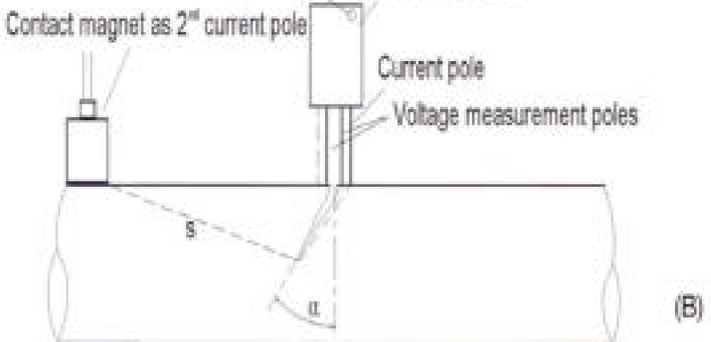
7. Conclusion

The crack depth measurement according to the potential probe principle, up to now accompanied by many uncertainties, is converted into a reliable and comfortable measuring method by the RMG 4015. The reduction to pocket size, the simple operation of the probes, the easy program and the low price offer the RMG 4015 as a low-cost, economic, simple and reliable control instrument; a useful supplement of the magnetic particle examination and penetration testing. It is always recommended when, for bigger or expensive workpieces, a reworking is needed, or when a crack growth (e.g. in production lines) has to be observed.

Fig. 7: Special probe to measure inclined cracks



A: First measurement U_A to determine angle α



B: Second measurement U_B to determine angle α

Fig. 8: Functional principle to measure inclined cracks