COERCIVITY METERING AS THE BASIC METHOD OF A NON-DESTRUCTIVE TESTING OF FATIGUE AND AS THE PRIORITY METHOD IN THE DIAGNOSTIC SET

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Here *"coercivity metering" or "coercimetry"* (c.m.) means a non-destructive testing of the mechanical properties, deflected mode and fatigue capacity based on measurements of the magnetic characteristic of metal – i.e. coercivity. All listed below merits are most fully achieved when working with coercimeters (magnetic structurescopes) of SSE company. And it is so not because the authors represent this company but rather because these devices feature a number of consumer and technical merits, which those of other manufacturers do not. Among them, the main thing is the highest clearance insensitivity i.e. when the device readings depend only on the properties of the metal, they do not depend on confounding factors, such as protective coating (paint, film, etc.) up to 6 mm (!) thick on the tested metal, or equivalent to such clearance corrosion layers, roughness, curvature of the surface, etc.

Statement that coercimetry today is most effective for assessing the fatigue state of the metal, even more so, as widely applied method, can be easily verified. One should take a typical specimen for testing mechanical properties of regular structural steel and load it with incremental tensile force on a test bench till its failure, record stress-strain diagram and simultaneously measure the coercivity value of the metal in the area of future failure with our device (for example, MC-04H-2). Then obtain another diagram of loading, stress vs. coercivity or deformation vs. coercivity. Coercivity here may increase from an initial value of the metal (as-delivered condition), on the way to its failure, 2 ÷ 4 times (!), depending on the brand of metal. In this test, the specimen is subject to planar uniaxial stress loading. This is the simplest version of simulation of actual fatigue process that occurs in reality. In actual operation conditions, metal is rarely subjected to such refined loading. Typically, there occurs a 2 ÷ 3-axial loading in combination with a set of degradation factors that accelerate the emergence, development and accumulation of micro-damage of the metal. Often it is a combination of static (constant and slowly changing) and cyclic loading (with different frequencies and amplitudes, including also vibrations), aggravated by temperature, corrosion, weather and climatic factors. To this multitude of loadings are also added: loading the structure with its own weight in combination with operational technological and mechanical effects, etc. An exhaustive list of all these effects would be longer than this report. But within this vast range of effects there plays its part an important, simplifying inherent property of the coercivity, systematizing such a complex manifold. This property lies in that the magnitude of the coercivity of the metal is continuously and noticeably increasing, becoming times higher than the initial magnitude, while the metal passes through the stages: from as-delivered condition to its final state: failure. Initial and final values of the coercivity of each brand of metal are its typical constants. In so doing the final value does not depend on how many and what operating factors led to failure of the metal. These two values of the coercivity: in the initial state (as-delivered metal) and in the pre-failure state are as significant parameters for each grade of steel, as for instance ultimate strength and yield strength. They can be easily measured on the spot. For the most widely-used grades of structural steels we have summarized such data in the table published in our articles, they can also be found on our website. The difference between these two values of the coercivity (initial and final) is identical to active life of the metal. Increment from initial to some intermediate, current value of the coercivity corresponds to its past life, while the difference between the finite and this current value corresponds to residual life, based on actual degree of accumulated fatigue. Moreover, the difference is based not on hypothetical mechanical properties of steel as they are cited in a reference book, which in reality change significantly during operation of the structure in the areas of loadings concentration (the weakest link of the diagnosed structure), but rather on true, real at any current moment state of the metal with all the features of a multitude of possible operational impacts on it, reflected integrally in the value of its current coercivity and the rate of degradation of the metal: rate of the coercivity increment, referred to the time during which this increment was taking place. From this rate of accumulation of micro-damage it is possible to quite accurately, provided loading conditions are known, to predict the transition of metal into an inadmissible state, when it is no longer able to safely carry out its functions in the structure.

From all the above it quite clearly follows that coercivity today is an incomparably effective informational parameter of nondestructive testing of fatigue micro-damage of metal, while successful implementation of our measuring instrument of the coercivity, makes coercimetry as of today most suitable for conducting quantitative monitoring of fatigue, a routine testing procedure.

Statement of the priority of coercimetry in the range of diagnostic methods is based on several obvious, i.e. axiomatic assumptions.

1. Fatigue defects are the result of micro-damage of metal. Therefore, an unbiased assessment of the current state of the metal should be made from the data on its fatigue condition and defects in it. Modern diagnostics is based primarily on the flaw-detection information, because in real practice of mass non-destructive testing, there are no devices and methods of practical assessment of fatigue, but for coercimetric ones, which we began to apply for these purposes now.

Today coercimetry allows methodically and instrumentally, fast, easily and cheaply identify and qualitatively and quantitatively assess changes in stress-strain and fatigue states. This ensures completeness of the initial data necessary for diagnostics. Measurements are made without scraping metal surface and using contact fluid, directly through a protective coating 5–6 mm thick. Nothing, except fatigue changes in the metal, will make a good coercimeter show intolerable values in the given area of testing.

2. In zones of stress concentration and other contributing effects, accumulation of fatigue micro-damaging is the first to appear. When a certain micro-damaging level is reached (each brand of metal has its own), it makes sense to carry out also flaw detection procedure. Up to this point fatigue defects in the metal are just not present at all. Such a pinpointing, selective approach reduces the scopes and cost of diagnostics, while its reliability improves.

3. Dimensions of zones-concentrators are substantially larger than those of inevitably arising in them fatigue defects, location of such zones is not accidental, but is predetermined by the design logic and logic of distribution of applied loadings. Therefore, the fatigue zones, being larger in size and logically arranged, can be identified by coercimetry much simpler than defects in the metal by means of flaw detection, as the defects are distributed, always and everywhere, fairly randomly.

4. Numerical coercimetric assessment of metal degradation makes an abstract until now concept of fatigue into verifiable, accountable process with accurate quantitative criteria of the degree of fatigue and lifetime of the metal. This makes it possible to use the whole lot of statistical methods and evaluations, which reduces subjectivity and improves visualization of the results. Diagnostics becomes more accurate, proactive, objective and predicting, with a renewable data bank regarding fatigue of a facility and all its elements during the service period. High sensitivity of coercimetry to damaging of metal allows to reliably monitor the corresponding changes in it from the moment of fabrication and erection of structures and hardware, long before dangerous level of fatigue processes is reached, up to the moment of macrodefects appearance.

5. Quantitative evaluation of fatigue of the metal enables creating an integral numerical characteristic of the whole facility as a weighted sum of similar coercimetric values - fatigue characteristics of its constituent units or structural elements. This integral factor clearly shows relative and absolute degree of wear of hardware, quality of its operation. On this basis, one can take substantiated decisions regarding priority, feasibility and scope of repair, such decisions being not random, but based on real metal condition, taking into account exactly unacceptable fatigue damage range. Thus can be worked out the most effective operational strategy for an industry,

company, department, facility, maximizing output of machinery at minimum cost, which is still referred to only as a hypothetical possibility in manuals of technical audit, because there was no test parameter for implementing such an approach.

6. If measurements of the coercivity were first to make, as *review* ones, then one can quickly get a general idea of the real current state of the facility. Here, at once are clearly visible zones of stress concentration and the degree of degradation of the metal in them. This allows reasonably "resort-not resort " to other methods of metal monitoring, depending on the actual state of fatigue, including fault detection in all its varieties, but now in precisely delineated areas, and volumes.

To make coercimetric monitoring quantitatively substantiated, normatively reasonable and always comparable and reproducible, we have solved the problem of obtaining standard of stress-strain state representative samples. They allow for each stage of "operation" of metal of a given brand, from its delivery to failure, by measuring its coercivity, to qualify its condition based on equivalent unit stresses and degree of fatigue degradation of metal.

Properly implemented addition of a novel, complementary method: coercimetry, to a set of diagnostic methods for examination of metal, paradoxically, reduces the price of the diagnostics, because overall scope of testing of the metal is reduced, while reliability of operated machinery increases, because testing procedures are conducted in the required scopes and in the right places, - zones of high fatigue, at the right time, i.e. from the moment of their "maturation" for development in them of fatigue macrodefects. Coercimetry here can reasonably extend the life of the equipment beyond its designed life, if the metal is still in working condition, or conversely – timely, ahead of schedule stop hardware operation, should unacceptable fatigue level of even defect-free metal be reached.

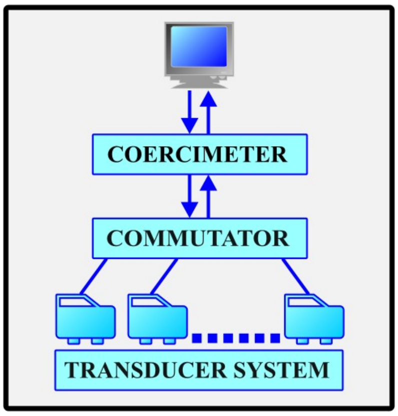
Without any doubt, coercimetry neither denies nor cancels presently used traditional set of diagnostic techniques. It only removes the historical imbalance in accents, complements diagnostics with previously unavailable diagnostic information, makes diagnostics more logical, complete and effective. Today this set is rather a formal list of testing procedures, regardless of the current state, regardless of the actual efficiency of information procurement by these procedures and in general, without any evaluation of metal fatigue in real life. It seems that it would have been more than appropriate in training ND professionals in any methods, to accustom them to the fact that metal is not a kind of fossil, in which their task is "to find or not find" defects. This is, in its way, a living and evolving system, with its initial, mature and final stages. At each of these stages for obtaining a comprehensive picture of the state of the metal, a different set of methods and in varying scopes would be effective. And coercimetry here, very meticulously considered, appears to be the most universal (after visual) survey method, equally effective and in demand at all stages of the life of metal structures and machinery.

Depending on the peculiarities of the tested facility, technical and economic feasibility, the required degree of security, coercimetric monitoring of metal fatigue can be performed 1) from time to time, or 2) continuously.

1) Periodic monitoring is performed manually or using mobile diagnostic robots. Such a robot is capable of round the clock, high-performance diagnosing the state of any difficult to reach or presenting danger parts of the surface of tested facility, also without suspending its operation. In so doing, it does not need metal surface scraping, it does not use any contact liquid and, of course, is never tired of work. When using our noncontact EMA-thickness gauges, the robot performs the two-parameter monitoring of metal condition, measuring the degree of fatigue and stresses, together with residual thickness (and defectiveness). Such combination is diagnostically very productive. Past experience shows that there is no threat to safety, if reduction of residual thickness of metal is not accompanied by increased coercivity, while reduction of thickness in combination with increase in the value of the coercivity is a compelling evidence of the impending failure of the metal. In some cases of manual testing, very productive is not the traditional transposable coercimetric transducer, but rather a

movable rolling one. Availability of such a transducer is a fundamental condition for constructing a coercimetric robot.

2) Continuous monitoring of fatigue and stress state of structures and machinery is carried out by our multi-transducer systems of stationary coercimetric monitoring. They enable control stresses, by varying within allowable range technological processes of operation of the tested equipment to prevent development of dangerous levels of metal condition. In so doing also clearly visible are main trends of systemic fatigue development in the facility, become more obvious reasons for this, and quite obvious are preventing actions aimed both at prolonging the life of hardware and its timely repair.



In the diagnostics, on the basis of such a concept of coercimetry, becomes a practical reality transition from underproductive search of defects to preventing failure of the metal. The essence of industrial safety activities will be the prevention of accidents, rather than clarification of their causes, as is the case today.

Addition of coercimetry to the range of testing methods is objectively beneficial to all participants of the diagnostic process: customers and contractors, as it is improving their awareness, competence and consistency and, ultimately, their well-being. For wide practical use of this approach, a set of new regulations and correction of existing ones is required. However, present condition of the system of their adoption and changing is aimed rather at preservation of the existing situation, than at its development. So we expect support from NDT community in this undoubtedly advantageous to all of us matter.

The report provides practical examples supporting all the mentioned findings and assertions. For more information please visit our website www.snr-ndt.com.