Evaluation of the Fatigue State of Equipment from Austenitic Stainless Steels According to the Degree of Acquired Ferromagnetism and Accumulated Microdamages by Nondestructive Method to Measure the Magnetic Characteristic, the Coercive Force

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Abstract. In stainless austenitic metastable steels both at the steel production stage and during the operation life, respectively occur technological and operational phase transformations, which results in the accumulation of ferritic phase, the percentage of which is greater, the greater are the impacts on metal. In the manufacturing process, these are heating and deformation. During its operation, these are heating pressure loads and other operating parameters, which lead both to ferritization, and fatigue type degradation, accumulation of damage at micro level. Moreover, both processes are mutually reinforcing. In practice most effective monitoring of such two-parameter degradation can be carried out using a non-destructive method to measure the magnetic characteristic, the coercive force. It increases during the degradation process (starting from an initial non-ferromagnetic state, till its failure) from zero to about 25 A/cm.

These performance limits are very specific for each steel grade. These are determined by bench tests of the samples. Similar characteristics are presumably observed both with martensitic and martensitic-ferritic stainless steels. We perform our coercimetric measurements using portable self-contained coercimeters with attached transducer directly on operated equipment, without grinding and without contact liquid at temperature of the metal reaching 600 degrees C, spot-wise or continuously, manually or automatically, nonstop or in sleep threshold mode. Such monitoring enables to estimate the rate of degradation of equipment and its components made from stainless and initially non-ferrous steel. Based on the rate of increase of the coercive force and its known boundary value at the beginning of the failure, one can forecast remaining service life based on the current coercimetric state of the metal. It becomes possible to assess the current state of fatigue of equipment made from stainless non-magnetic metal based on the degree of ferromagnetism acquired and level of accumulated fatigue-type micro-level damage.

In stainless austenitic metastable steels both at the steel production stage and during the operation life, respectively occur technological and operational phase transformations, which results in the accumulation of ferritic phase, the quantity of which is the greater, the greater are the impacts on metal. In the manufacturing process, these are heating and deformation. During its operation, these are heating pressure loads and other operating
parameters, which lead both to ferritization, and fatigue type degradation, accumulation of damage at micro level. Moreover, these both variations of physical transformations in metal are mutually reinforcing. It appeared that most efficiently practical monitoring of such two-parameter degradation can be carried out using a non-destructive method to measure the magnetic characteristic, the coercive force. It increases from zero to ~25 A/cm during the degradation of metal starting from an initial non-ferromagnetic state, till its failure.

These coercimetric performance limits are very specific for each steel grade. These are determined by mechanical bench tests of the samples. Similar coercimetric characteristics are (presumably) observed with martensitic as well as martensitic-ferritic stainless steels. We perform our coercimetric measurements using portable self-contained coercimeters with attached transducer directly on testing samples or directly on operated equipment, without grinding and without contact liquid at temperature of the metal reaching 600 °C, spot-wise or continuously, manually or automatically, nonstop or in sleep threshold mode. Such monitoring enables to estimate the rate of degradation of metal of equipment and its components made from stainless steels. Based on the rate of increase of the coercive force and its known boundary value corresponding to beginning of the failure, one can forecast remaining service life based on the current coercimetric state of the metal. In so doing it becomes possible to assess the current state of fatigue of equipment made from stainless non-magnetic metal based on the degree of ferromagnetism acquired and level of accumulated fatigue-type micro-level damage.

The basis of the above were made by us tests of samples of several varieties of stainless steels 12X18H10T (chemical composition: C – 0.98; Mn – 1.33; Si – 0.66; Cr – 18.2; Ni – 10.6; Ti – 0.66; Mo ≤ 0.1; S – 0.003; P – 0.40) and 08X18H9 (C – 0.036; Mn – 1.73; Si – 0.42; Cr – 18.2; Ni – 8.2; Ti ≤ 0.1; Mo ≤ 0.2; S – 0.003; P – 0.028). Tension test specimens were strip-shaped. Samples for cyclic hydraulic internal pressure tests were in the form of pipe segments diameters 73 and 42 mm and wall thicknesses of 3 and 1 mm, as well as spherical hollow cylinders diameter 130 mm and wall thickness 3 mm. Cyclic tests were performed in the low-cycle fatigue mode. All test samples were loaded till their failure. the coercive force of the metal has increased from zero to 45 A/cm. Simultaneously with coercimetric measurements were performed measurements with ferritometers under the assumption that it allows to control the content by volume of ferrite as a result of phase deformational metal transformations. Volume increment of ferrite content (in the process of bringing the metal to fracture) from zero to 39% was detected.

At the beginning of metal degradation ferrite appears due to the decomposition of austenite. As the degradation progresses, increase of the ferrite phase is accompanied by accumulation of its fatigue damage. This increases the coercivity of the ferrite phase to its natural zero value to the above levels. Fatigue Damage of non-magnetic phases at the same time indirectly also promotes the growth of coercivity of ferromagnetic structures, which are here carriers of the damage in the area of magnetism, where it becomes available for high-performance in the field of magnetic measurements. Reported here phenomena suggest the possibility of formation of a new type of chart of state of solid carbon-doped iron solution. In it phase and structural transformations occur depending not on the temperature of the solution, but now on the quantity of mechanical energy destruction under loading. This type of chart can be fundamental to the understanding of the processes of fatigue degradation of any steels, but especially, stainless ones (during their service).

If approached empirically, the results at hand are quite sufficient for organizing operational coercimetric monitoring the current state of stainless steels. It is only necessary for each metal bench to perform staged bench mechanical tests of samples for the detection limiting coercimetric borders of the beginning of destruction of metal. Current state of the coercive force increases from zero up to this limit value with increasing metal fatigue degradation. The coercive force is preferable and more informative than ferritometry to
assess the current degradation because it is simply measured directly on the operating equipment, regardless of the state of the controlled surface and allows for the amount of appearing ferrite and degree of its fatigue damage. Ferrite in solving these problems contributes to the ability of using a much more effective (informationally and instrumentally) coercimetry.

The coercive force method is most effective in the technological and diagnostic tasks when applied to the ferromagnetic steel and cast iron. Current issue of the fatigue monitoring of stainless steels today actually has no practical solution. Their ferritization during fatigue type degradation can be used for non-destructive monitoring on a practical level, is well spent instrumentation and methodical support of the coercive force method also on this originally a non-magnetic metal. The results of bench tests show that here, due to lack of masking original ferromagnetic background, coercimetry manifests itself as an even more sensitive and more dynamic informational characteristic of the fatigue degradation than on ferromagnetic steels and cast iron. The ferrite phase here is a necessary specific transit, a carrier for use of exclusively effective in solving problems of fatigue monitoring of magnetic non-destructive coercive force method.

The report is accompanied by the results of tests of samples and methodological features of all research works.