Practice of Monitoring of the Stressed Condition, Fatigue and Lifetime of Welded Joints as Per Measurements of Magnetic Charecteristic – Coercive Force

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Abstract. Coercive force is an efficient parameter in non-destructive testing of fatigue changes and residual stresses in welded joints. Standard samples of stress-strained state of metal were manufactured, specialized diagnostic complex, consisting of coercive force meter and pocket personal computer was developed. Reported are the results of testing welded joints of pipelines of a nuclear power plant – new, repaired and those at end of their service life.

Principal for coercive force measurements in operational testing of metal structures and equipment assemblies, including also welded joints, are not defectoscopy problems, but level of fatigue changes, especially in a still flawless metal. Namely this is what present-day diagnostics is lacking, which with its growing expenses on defectoscopy of all types, does not provide a required dynamics of accident rate reduction. Transition in operational diagnostics from practice of search for flaws to a more efficient their prevention, is possible now only on the basis of testing of fatigue state of the metal. Without such testing credible evaluation of equipment lifetime is impossible. In acceptance and technological testing of new welded joints, when fatigue problems are not at issue yet, coercive force measurements enable to evaluate the quality of welding, while monitoring residual stresses and the degree of their relieving. Phase conversions in metal in the zones of seam and those of thermal influence, the degree of inhomogeneity of the seam against the background of the base metal (as one of the prerequisites of equal strength), are also well monitored, both qualitatively and quantitatively.

Prior to our use of coercive force measurements at the beginning of the 90-ties in solving problems of operational monitoring of metal, experts did not have in their disposal an effective parameter of non-destructive testing in tackling such problems. To say nothing about their accessibility for wide use by rank-and-file personnel, and a convenient instrument implementation. Such a combination of methodical and practical advantages became possible in the approach, described below.

From destructive bench (static and cyclical – low-cycling fatigue) tests on samples of different grades of structural steels, also from test loading of actual facilities (for instance oxygen cylinders, pipeline sections), it was established that coercive force grows by 100÷300% (depending on metal grade), as the tested metal changes from the state it was in at the time of delivery, till its failure. It is a very high sensitivity to accumulation of fatigue degradations, which is unavailable with other non-destructive testing parameters. On this basis, after investigation of hundreds of pressure vessels and load-lifting cranes we have

manufactures standard samples of stressed-strained state of metal for various grades of structural steels, we also worked out rules of technical diagnosing (with evaluation of residual lifetime) of load-lifting cranes and pressurized vessels.
Our application of such an approach already for diagnosing of welded joints (with regard for their specificity as tested objects), enabled to obtain even more efficient results. Clear, that in a welded joint, beside classical fatigue degradations of metal in the seam and in zones of thermal influence, it was important to "see" also residual welding stresses, evaluate efficiency of their relieving by heat treatment, and in the process of their operation also "discern" incipience of zones-concentrators, as forerunners of future failure of the seam. Here residual stresses add-up with structural ones, all that is topped-up with operational loading and aggravated with accompanying factors (temperature, vibrations, aggressive media, etc.). In such a concentrator in operation of an equipment a kind of specific repeating sequence of processes aggravating each other by exponential, is building up: the above stresses and operational loads add-up, accompanying operational factors → accelerated corrosion of all types and phase conversions of the metal → reduction of section area and loss of plasticity reserves → growth of specific loads → etc., again repeating the same cycle, along with accumulation of fatigue changes, up till the metal failure in such a concentrator. In reality some elements in such a cycle can fall out or follow each other in other sequences. But the end result is the same – metal failure. Important is the fact that all that is accompanied by a reliable forerunner – permanent and accelerated local growth of coercive force values in the area of such a concentrator. And, what is not less important, all that occurs in a defectoscopically perfect metal. That means that coercive force measurements at this stage are the only source of obtaining the efficient parameter of indirect monitoring of the development of degradation processes in the flawless metal. Fatigue flaws are an inevitable result of those processes.
Appearance in wide use of the so-called pocket portable computers (PPC) enabled to solve also the problem of promptness of coercive force measurement. Previously end result was obtained not right at the site of testing, but only after processing of coercive force measurement data on computers in diagnostical centers.
Now in the new complex (coercitimeter + PPC) the operator right away sees on the display the state of the whole tested metal zone. The coercitimeter is connected with PPC through a standard wireless channel. It is very convenient, since, not rarely the measurements are conducted amid equipment piles and intermingling technological pipelines, as is the case with nuclear power plants. The operator is busy only with coercive force measurements. Gathering, sorting and processing of coercive force measurement data is effected by the PPC itself, data coming through radio channel. On completion of the measurements the results can be seen on PPC display, they are: 1) table of measurements, 2) histogram of the obtained set of values, 3) geometrical development of welded joint with overlaid information on the seam metal state and near-seam zones as a descriptive color chart of levels of coercive force values. Table of measurements contains the most complete information on the subject of testing, but in the least descriptive form. To improve "readability" of the taken readings, the PPC converts the original table into two resultant demonstrational varieties – histogram and development. In the histogram, not seeing the subject of monitoring, one can at once evaluate overall state of a welded joint. But it is impossible to indicate the location of dangerous zones and the degree of degradation of each of them. Such information is reflected in the development. The histogram is displayed on PPC, with indication of its two main digital characteristics, quite informative for welded joint metal state – mean value of coercive force measurements, mathematical expectation (ME) and root mean square deviation (RMSD) – degree of scatter of those measurement results with respect to the mean ones. Those two figures convincingly characterize the quality of welding and heat treatment technologies, and, if monitoring was conducted on a

new or a repaired seam – the better the technologies are, the higher are the values of ME and RMSD, hence slower they grow as a function of reduction of the plasticity reserve of the metal, that is use-up of the lifetime. The histogram, ME and RMSD are useful both for prompt evaluation of welded joint metal state, and of the quality of welding technologies, as well as for numerical monitoring of the dynamics of accumulation of operational fatigue of the metal.

However the histogram, by its statistical nature, because of the averaging of initial measurement data, in its construction, loses its original tabulated information on the location of stress concentration zones and the degree of defectiveness of each of them. All that is clearly seen already on the development of a welded joint, where in color is shown distribution of coercive force measurement values, enabling also to see the degree of inhomogeneity of the seam against the background of the base metal.

Introduction of computer technologies in this case was carried out as an intrinsic means of enhancing application capabilities of the instrument and the method, which neither impedes nor weights upon the non-destructive testing expert. PPC only monitors his testing work, not interfering with it. And, when necessary, the computer shows the expert the measured values, as well as ready-to-use results of their analysis, and all that is available in the most descriptive form. Further, in the near-weld zones, satisfactory in the context of coercive force measurements, possibility of detecting fatigue flaws is almost zero, as they are not present there. Flaws, all be it present in such a place, can only be "sleeping" ones (of metallurgical or welding origin), not affecting either resistance to loading, or stress-strained state of the metal, and, consequently, not affecting coercive force of the metal in the zone in question. In this way coercive force measurements do not negate, but intrinsically complement with new information all that has been accumulated by now in traditional diagnostics, in defectoscopy.

Systematically observing the histogram, ME, RMSD and seam development during operational period, using coercive force measurements, it is easy to detect incipience and the degree of development of future failure zones, since the process of formation of such zones is not a sudden, avalanche-like process, it can take years, therefore it is easy to detect in periodic testing. Possibility of detecting zones of concentration of loading is much higher, than of the flaws, since dimensions of such zones are much greater than dimensions of the incipient in them flaws. Location of such zones is not accidental, but is logically pre-determined by the structure of the articles, distribution of loading in them. Reproducibility of the results of coercive force measurement in testing is always practically one hundred percent (provided the personnel careful enough), because of simplicity of the method and significance of the revealed changes in metal state, both with regard for dimensions of zones-concentrators, and with regard for increment of changing value of the informational parameter in those zones – coercive force value. Anomalously high values of coercive force increment in metal of the tested zone during the period between tests are a reliable, not prone to falsification testimony of abnormal overloading or disturbance in loads distribution in the tested structure.

The degree of proximity of current metal state in each specific zone to the pre-failure state, is unequivocally evaluated based on the greatest values of coercive force in such a defective region. Applying in such cases methods structurally unloading such zones, as well as technology of regeneration of metal properties, in operation practice one can turn from flaws search to their prevention, forestalling also connected to it failures in equipment operation. In so doing coercive force measurements show the flaw detection operator most likely locations of future fatigue flaws. Time spent on evaluation of the state of one welded joint is from one to several dozens of minutes, depending on the seam length and complexity of its configuration. Thus, for a circular seam on the pipe having diameter 1420 mm it does not exceed 30 minutes, which is quite not much compared to the importance of

information obtained at this. Scraping the metal is not or almost not required. Testing without removal of protective insulation on the pipeline is also possible. Our coercitimeters for testing welded joints can be complemented with new converters on a cart instead of those transposed ones. It enables to measure coercive force, but not discretely, in the testing points, but continuously, along the line of movement of the hand cart. It improves productivity and information output of testing process.

Since stored in PPC table, histogram with ME and RMSD, Hc-chart with seam development is a set of ready-to-use formalized complete information on metal state, thus on such a basis in an easy and simple way an efficient computer database is formed for each seam of the tested object, during its whole operation lifetime.

Portable diagnostic complex (coercimeter + PPC), enhancing coercive force measurement capabilities with computer means, enables one in a simple way, quickly evaluate fatigue and stress state of any welded joint or any metal structure or equipment assembly. It is a new level of diagnostics, when rich defectoscopic traditions, efficient, but only at final stages of equipment operation, for the first time and intrinsically, are complemented with monitoring of the degree of fatigue of the metal, which yields results already from the moment of manufacture and assembly of the equipment and during the whole period of its operation. Turning over to prevention of flaws instead of less productive tactics of their search becomes a reality, available for a rank-and-file expert, at the accessible and understandable to him level.