NEW POSSIBILITIES OF NDT OF NUCLEAR REACTORS FRAME ON THE BASIS OF METAL MAGNETIC CHARACTERISTICS MONITORING

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Abstract: On the example of condition testing of “problem” welded joints of the first circuit by the measurements of magnetic characteristic of – coercive force of metal – we have shown the practical effectiveness of this parameter for estimation of fatigue condition of equipment of power units caused by net effect of constructional loads, working pressure and temperature. In order to estimate the degree of irradiation embrittlement of RVP, as measurements on the samples in hot cells have shown, it is practically reasonable to use characteristics of magnetic conductivity. We have designed and tested devices for measuring of these characteristics in the operation conditions of power units of an A-plant.

Introduction: Experience of 30-year's maintenance of reactors with water under pressure (WWER) has shown, that the traditional tracking methods of metal capacity of A-plant primary equipment do not solve all estimation problems of actual degradation level, as they are basically oriented on metal defectoscopy and mechanical testing of the reference specimens. Having been perfected the metal operation testing in atomic engineering actually only states and traces the already formed defects, when much longer and better observable process of fatigue zones origin, their development, at first on microlevel and then conversion into macrodefects, is not present in any way at the existing system of operation diagnostics. On closer examination it appears, that now diagnostics per se means defectoscopy and the problem of resource evaluation is reduced to the problem of estimation of the detected defects number and their development rate. The level of modern concepts and cost of man-caused breakdowns urgently demand other approaches with the stress made more on preventing the operation defects but not on their detection. Substitution of diagnostics by defectoscopy (and even identification of these concepts) took place in nondestructive testing (NDT) long time ago and everywhere and apparently was historically conditioned. At the same time it is now difficult to negate, that despite growing expenditures on diagnostics the breakdown rate of equipment does not decrease, and if there is a decrease then it’s absolutely incommensurable with the money put up in NDT. It convincingly testifies to incompleteness of the existing now metalware testing system. This incompleteness first of all seems to take place because the system of diagnostics obviously lacks practical non-destructive tracing methods of fatigue modifications accumulation in metal and tracing devices. The duration of metal construction’s “life” before fatigue defects in metal occur is known to make the most part of service life. Thus appears a situation of surprisingly obvious unproductiveness, when during the most part of service life the diagnostics (as it is usually understood today) is not effective. It can mainly only determine defects and track them. But the metal of just started to work equipment is not supposed to have defects for a long time. And such diagnostics – defectoscopy cannot foresee and especially prevent fatigue defects, as at practical level of diagnostics there still have been no tracing methods and instruments of fatigue modifications development and accumulation in free of defects metal – reliable forerunner of fatigue defects, not to mention diagnostics of those objects, which maintenance does not admit any fatigue defects. It’s also not a secret, that the detection probability of metal defects in the ordinary ultrasound defectoscopy of active equipment is low, at the level of 0,5. A reliable testing prognosis based on such probability statistics of metal defectiveness is impossible. Whereas the zones of fatigue modifications – zones of stress concentration (finally fatigue defects inevitably occur in them) – are not needed to search, their location is well known as it is stipulated by the building logic of a tested item construction. And the sizes of these zones are big, much bigger than the sizes of defects originating in them; therefore detection probability of each such zone is practically equal to one.

As it is shown in the report, there are NDT information parameters, which vary by tens and hundreds percents during metal degradation from the initial supply condition up to the limiting pre-destruction condition. Only at this limiting stage an intensive process of macrodefects formation, detected by methods of modern defectopscopy begins. The magnetic characteristic of metal – coercive force (Hc) – is one of most effective parameters of such kind [1]. And what is important, we have been designed and tested within long operation life devices – magnetic structurescopes – for mass NDT. In the concluding part of this report the outcomes of such

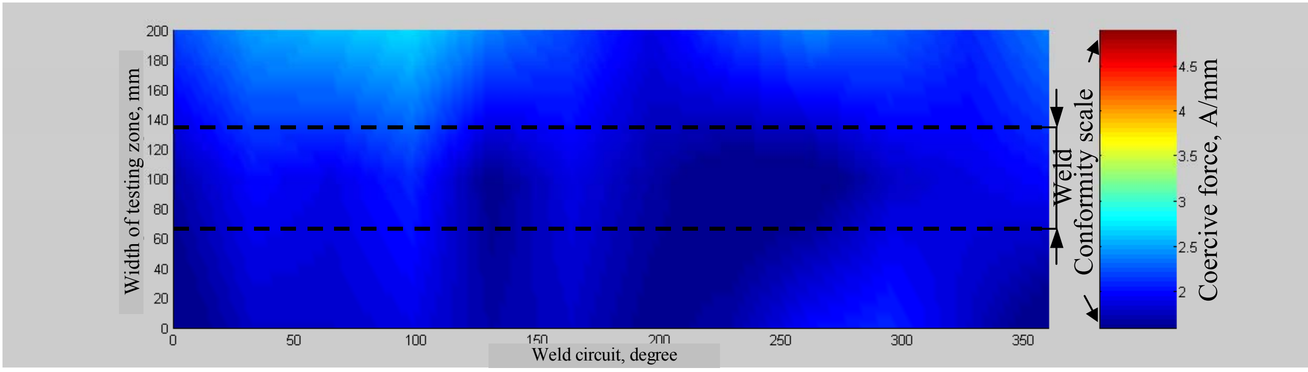
testing of metal fatigue condition on the example of A-plant equipment are given. It is not experimental, but real life work, and thus we solve a problem, which was inaccessible to mass diagnostics until now – quantitative and qualitative tracing of defects accumulation, i. e. fatigue condition of free of defects metal, besides at high level of reliability.

Worked out by the firm "Special Scientific Projects Development" (SSPD) (c.Kharkov) procedure and instrumentation of determination of metal life by metering and analyzing the coercive force, and other characteristics of magnetic hysteresis loop of the controlled power unit component show, that this approach is quite promising. The experience, gained while monitoring the mechanical properties by metering magnetic characteristics of constructions is concentrated in interstate CIS standard ГОСТ 30415-96. Since 1997 on its basis there has been allowed an authorized technical (on the basis of metal magnetic characteristics monitoring) testing of all types of hoisting cranes, vessels of pressure, pipelines and metallurgical equipment. Such diagnostics traces metal degradation of loaded equipment components under influence of the operation factors. And it is particularly important that such diagnostics is already effective at that stage of safe life, when there are still no metal macrodefects, i.e. those defects, which can be detected by defectoscopy.

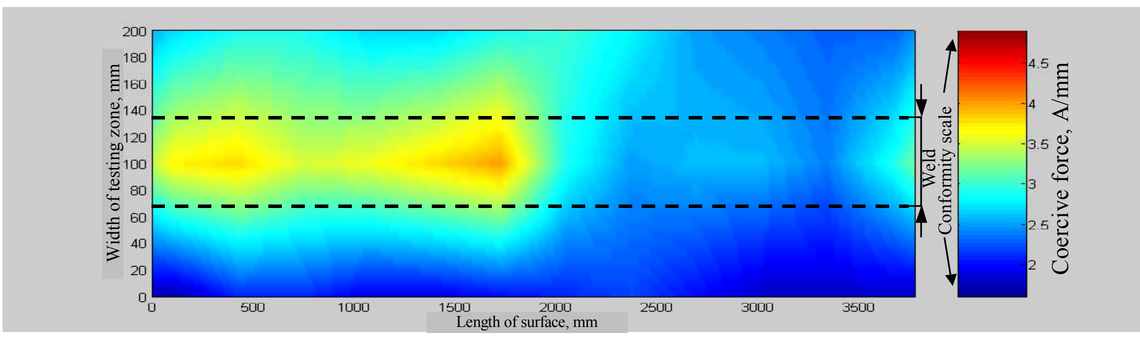
Results: An obvious case of diagnostics effectiveness by the results of coercive force metering is experience of examination of steam generators (SG) WWER. The problem of their reliability testing arose when on a nipple of the casing in the collector weld (weld №111) area there appeared cracks, which had not been detected by ultrasonic testing (UST) during scheduled inspection of the unit. Here we had the weld with diameter of 1350 mm and wall thickness of 72 mm (thermostable pearlitic steel 10ГН2МФА). It is essential that on some steam generators this weld behaved in operation perfectly, when on others emergency conditions indicated the tendency of renewals after each repair. Moreover such contradictory picture could occur on the steam generators of the same power unit. All attempts of the ultrasound testing turned to be ineffective.

In order to solve this problem during the scheduled stop of the unit we tested the condition of metal in weld № 111 in four SGs of the same unit and, to compare with, in two new SGs kept in storehouse reserve. Coercive force was measured along the perimeter of the weld and in weld-around zones above and below the weld. "CHP" company designed the methodology, metrology opening-up and portable device for diagnostics – magnetic structurescope КРМ-Ц [1]. The results of the testing are given in fig. 1.

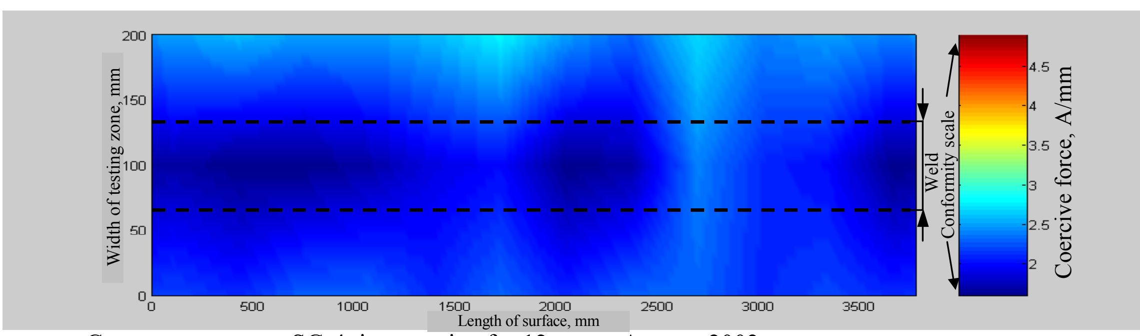
Fig. 1. Testing of weld №111 condition on 4 operating steam generators of the same power unit and on two new SGs.



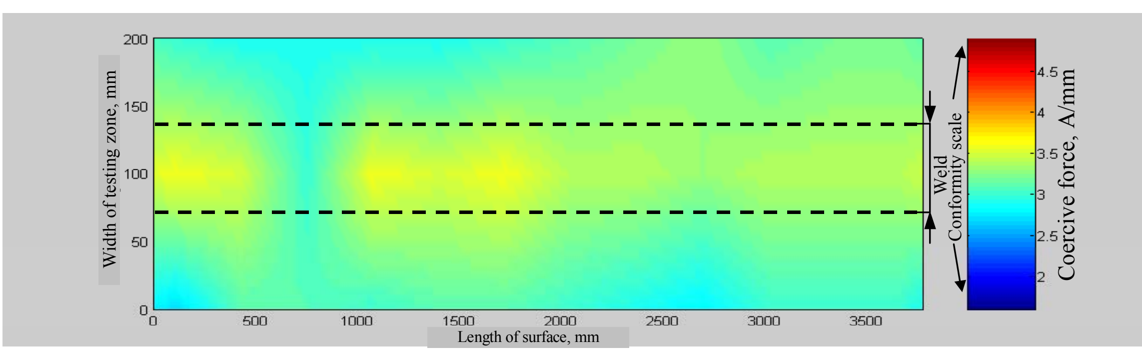
A - new steam generator, from storehouse.



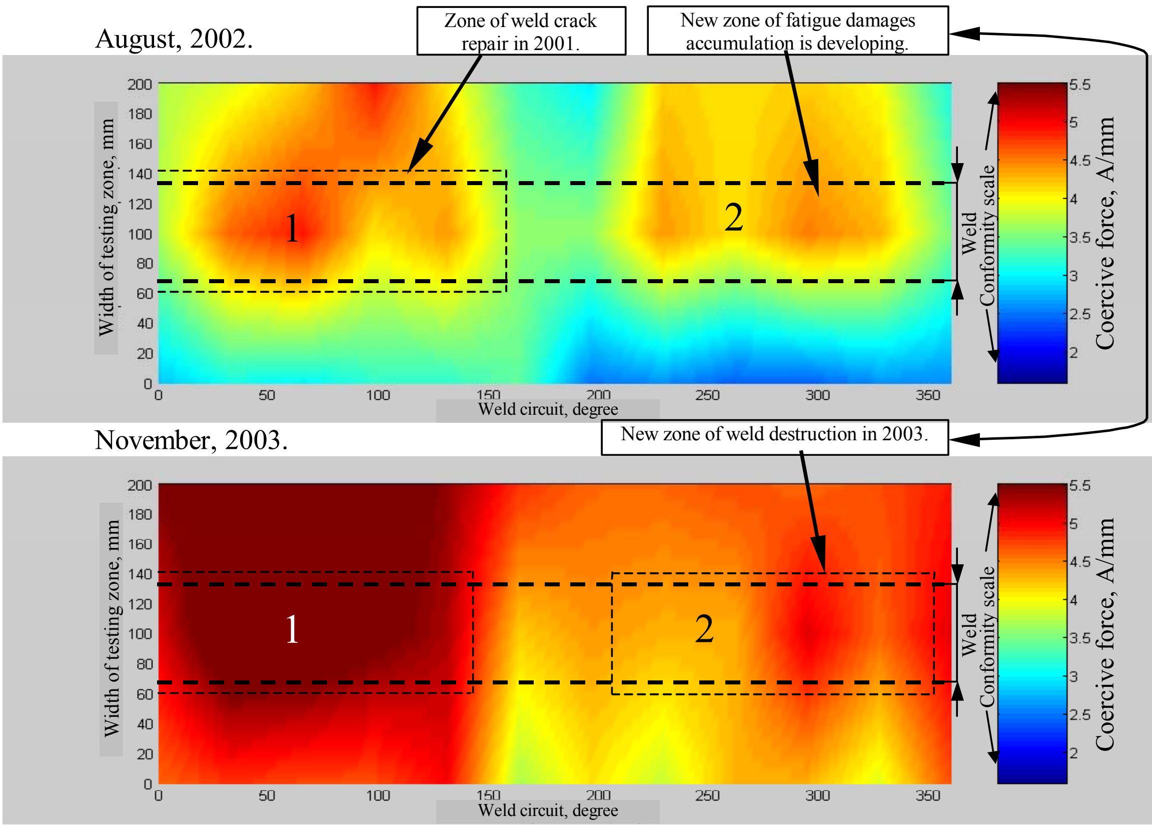
B - new steam generator, from storehouse, has weld anomalies, which can become the future zones of accelerated destruction.



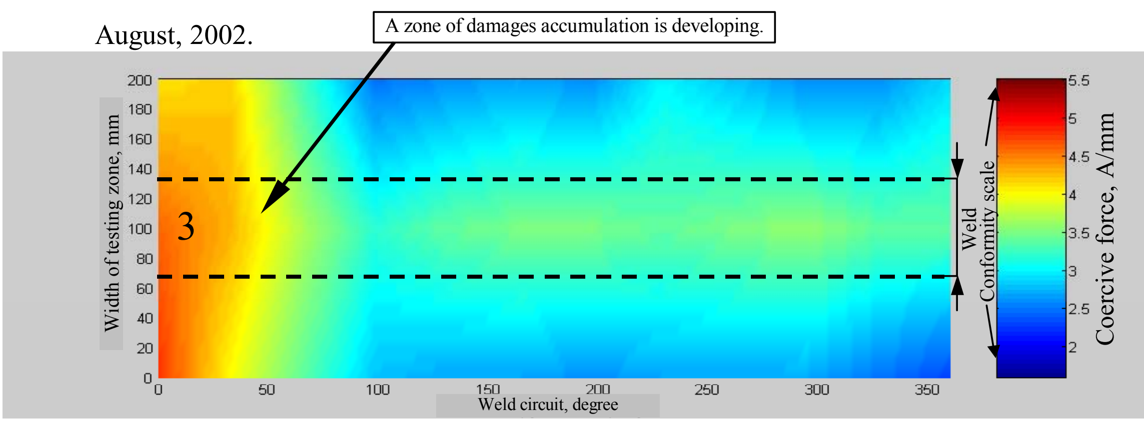
C - steam generator SG-4, in operation for 12 years. August, 2002.

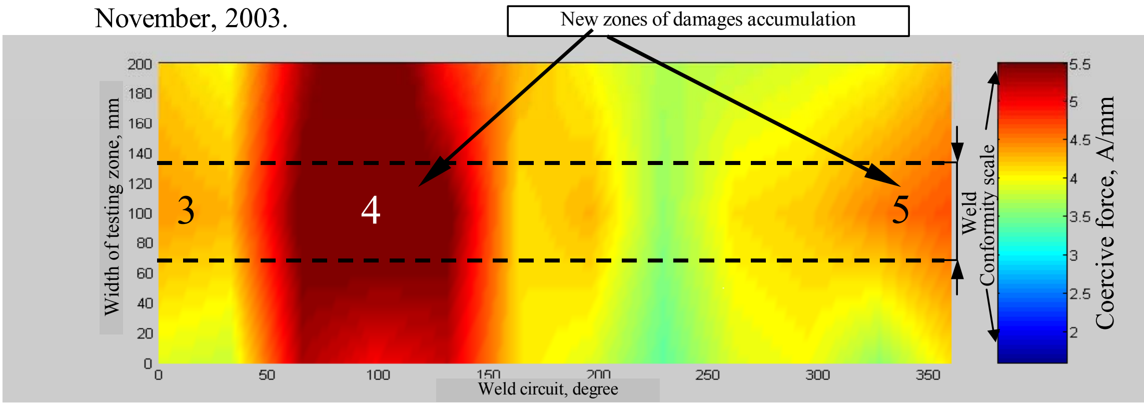


D - steam generator SG-3, in operation for 20 years. August, 2002.



E - steam generator SG-2, 12 years in operation





F - steam generator SG-1, 12 years in operation

Discussion: The analysis of the results allows making the following conclusions:

– Repaired a year before, in 2001, zones of weld №111 of SG-2 in one year, in 2002, continue to experience cumulative loads at the level approaching $\sigma_{0,2}$, Fig. 1E.

– The welded joint № 111of SG-4, Fig. 1C, has not accumulated fatigue stresses, though it has the same life expectancy, as SG-1, Fig. 1F, and SG-2, Fig. 1C.

– One of not working new SGs (fig. 1B) already has zones of heightened stresses in weld. Here more intensive diagnostic support is necessary during its assembly and maintenance.

– The condition of weld № 111 of SG-3 is characterized by normal natural level of fatigue damages accumulation. It can be seen from comparison of metal condition of welds SG-4 and SG-3 (fig.1C, 1D). The difference between them, worse for SG-3, is only explained by its longer (by 8 years) service life. Neither of these SGs have heterogeneous zones in welds. It is obvious, that these welds while in service are loaded uniformly and most likely do not experience other loads, except for working pressure and temperature.

– The welds on SG-1 and 2 (fig. 1F and 1E) besides these operation loads obviously have considerable and mainly bending, and partially torque mechanical constructional loads. And within a year after the first testing of these SGs in August, 2002 the intensity of construction loads increased essentially, the character of their allocation on the weld changed. Thus on SG-1 weld within a year of operation there appeared and developed up to limiting values of fatigue a zone in the area of 100^0 coordinate. The occurrence of such zone within only a year of operation can only be the result of extremely unsatisfactory allocation of loads in nipple construction, where this weld is. As a result – the probability of presence and development of defects in this weld zone is significant. Within a year the average Hc value on the weld of both SGs increased approximately by 1 A/cm with normal increase, as we consider, of no more than 0,1 A/cm. Such growth is characteristic only for metal in the zones of pure plastic deformations, what is incompatible with mode of reliable maintenance of such equipment.

Undoubtedly, the greatest effect is made by comparison of metal condition of the same weld № 111 jf SG-2, Fig. 1E., with an operation interval of a year, and similar testing of SG-1 weld, Fig. 1F. The coercive testing, conducted in 2002, showed unsatisfactory metal condition of SG-2 weld from the point of view of its fatigue condition, both in zone 1 of this weld, where a year earlier a through crack was repaired, and in zone 2. It is necessary to mark out that along with coercive testing at the same time, i.e. in August, 2002, the complete testing complex of weld№111 of this SG (as well as all other SGs) was conducted by standard NDT methods including, naturally, the most thorough defectoscopy. Thus no defects were detected; therefore by results of classical branch diagnostics the unit was put into operation without any limitations. A convincing proof of effectiveness and relevancy of carried out coercive testing was metal destruction in zone 2 of SG-2 weld№111 of this A-plant that happened with power unit emergency stop in a year of operation, in 2003. No other modifications in metal, except for fatigue modifications (in low-cycle fatigue mode) and simultaneous accumulation of structural damages, can "force" magnetic structurescope to show anomalously high values of coercive force, from 2 to 3 times exceeding the initial Hc_0 values, peculiar to new metal in delivery condition. From our experience of diagnostics based on coercive metering, metal destruction of weld№111 in zone 1 of SG-2 and in zones 3, 5 and especially 4 of SG-1 is a matter of the nearest future, since macrodefects arise in such zones with maximum level of accumulation of metal fatigue microdamages, or in other words with maximum values of coercive force for the given steel quality.

As we can see, everything here is absolutely physical and matches classical understanding of destruction mechanics. Coercive force metering has only allowed tracking metal condition at that very earlier stage of fatigue processes development, which remained outside of practical diagnostics before. The offered method of non-destructive testing is also supplemented by original, visual means of documenting and mapping of testing outcomes, which allows having computer database tracing quantitative and qualitative modifications of metal condition of each welded joint. It practically eliminates the subjective factor in such diagnostics, and also makes it possible to trace precisely the qualitative and quantitative dynamics of processes of failures origin and accumulation on a microlevel in the metal of main components directly on the unit.

Along with this the experts of "Special Scientific Projects Development" firm jointly with Radiation Materials Technology department of Nuclear Research Institute of Ukrainian Academy of Sciences have examined the samples of hull plate and welded joints irradiated in channels of reactor WWER-1000 as to total planned fluence (40 years of maintenance). It was pointed out, that the indexes of coercive force are a small degree connected with the level of radiation embrittlement. This parameter has appeared more effective in analyzing mechanical and temperature influence. For radiation embrittlement testing a parameter working on a microlevel and defining dislocation pattern inside separate metal grains is necessary. Having analyzed character of magnetic hysteresis loops in the irradiated and unirradiated samples, the experts came to the conclusion, that in this case it is necessary to work with the parameter of magnetic conductivity, which better reacts to radiation damages of metal lattice.

Fig. 2. Irradiation influence on magnetic conductivity of RVP metal.

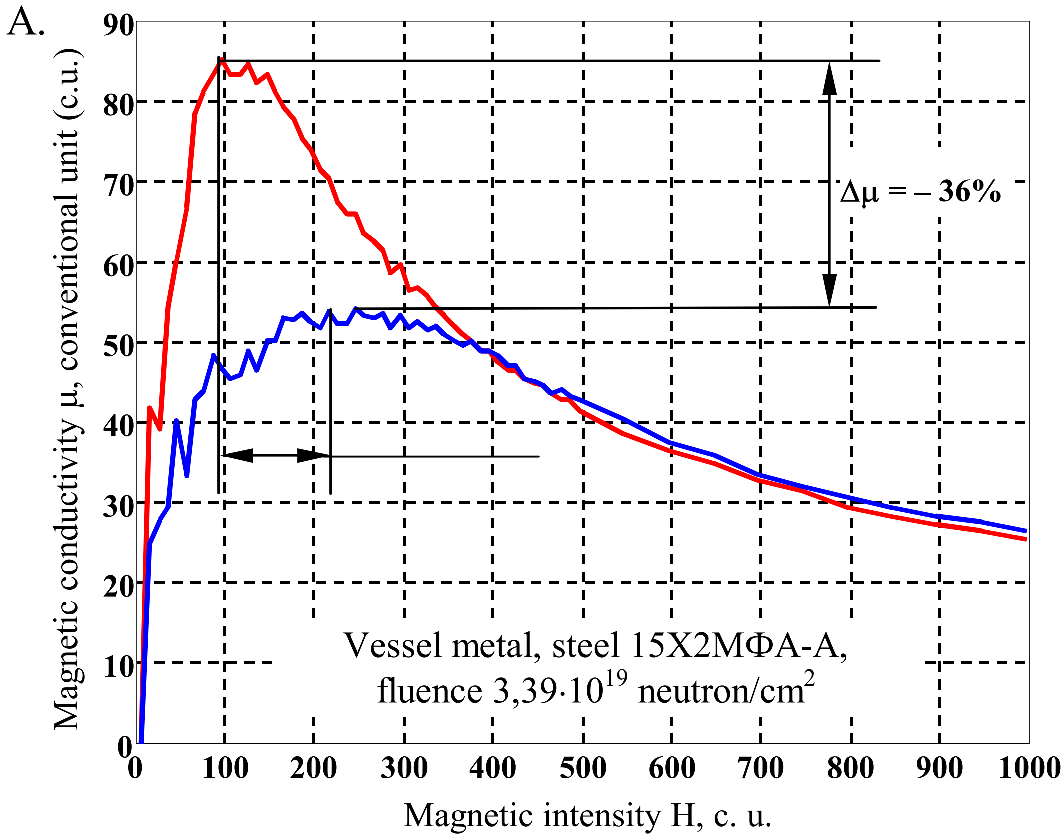


Fig.2 demonstrates the changes of magnetic conductivity μ of the samples of hull plate and metal of vessel weld after fluence of about 10^{19} neutrons/cm^2. It is visible, that both value of maximum of function μ(H), and position data of this maximum on axis H change. In the latter case increment ΔH has order of 100 %. And for weld metal the magnitude of this increment is also strongly linked with percentage of nickel. Graphs confirming the last fact are not given here because of the size limit of the given report. The obtained values of increments Δμ and ΔH, as fluence function, are quite acceptable for practical testing. We should point out, that on actual equipment these modifications would be even more significant, since for our magnetic analyzer КРМ-Ц-МА used for these measurements the mass of the tested metal is essential. We initially designed this device for testing actual equipment, but not small masses of metal, like used here full size Sharpi samples. The similar measurements made on the samples in hot cells in GRC, Petten, demonstrated good coincidence with measurements made in Kiev if to take into account that in GRC we had to work with mini-Sharpi samples weighted 4-5 times less.

Along with this sample testing experts of Scientific Research Institute of Nuclear Power Engineering (ВНИИАЭС) in Russia conducted a practical series of work at the first unit of Rostov A-plant before starting up in order to record the initial condition of its reactor vessel by means of magnetic characteristics testing. It was the first real step towards arranging practical testing of metal condition of the reactor vessel by measurements of magnetic characteristics.

Conclusions: 1. The long-term experience of coercive force testing received on components of critical constructions in other branches of engineering on basis of standard ГОСТ-30415, gives all grounds for applying these developments in nuclear power plants.

2. The researches conducted on separate components of nuclear power units prove this approach to be really advanced in determination of metal serviceability in realization of metal degradation control programs and programs of safe life extension.

3. The worked out methods and devices have been industrially approved, are user-friendly, have up-to-date software environment.

4. Monitoring of magnetic characteristics of metal on A-plant equipment (coercive force and magnetic conductivity) supplement the classical branch diagnostics with new, earlier inaccessible information about the degree of fatigue micro defectiveness accumulation in non-destructed metal already, and about the degree of irradiation embrittlement. This improves the accuracy of diagnostics and in practice allows prevention of emergency cases immediately after introduction of such testing and at any stage of power units operation.

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References: 1. V. Muzhitskiy, B. Popov, G. Bezlyudko. "Estimation of stress, fatigue and capacity of welds by measurements of magnetic characteristic – coercive force" Proceedings of 16 WCNDT, Montreal, 2004.