ESTIMATION OF STRESS, FATIGUE AND CAPACITY OF WELDS BY MEASUREMENTS OF MAGNETIC CHARACTERISTIC – COERCIVE FORCE (Hc)

V.Muzhitskiy[1], B.Popov[2], G. Bezlyudko[3]
[1]Scientific Production Enterprise "SPECTR", Moscow, Russia; [2]Engineering and Consulting Centre "KRAN", Moscow, Russia; [3]Firm"Special Scientific Projects Development", Kharkov, Ukraine.

Abstract: The results of metal testing in weld and weld-around zones as to degree of fatigue microdefects accumulation by measuring coercive force are shown. The approach has been well checked in regard to both method and instrumentality during mass testing of equipment. Tracing the fatigue factor of metal condition in all maintenance stages improves diagnostics quality, creates practical possibility for transition from tactics of defects detection to their prevention.

Introduction: Fatigue condition monitoring of metal constructions and their components on a level of equipment mass examination is not really made now. The main reason is absence of effective simple and cheap methods and devices accessible to an ordinary expert. Therefore not having such data the existing system of metalware technical testing operates mainly with both data and concepts of defectoscopy and fracture mechanics – defects detection, their number, cracks propagation rate, etc. However during the most part of safe life a correctly designed, produced and maintained construction has no fatigue defects. Though zones of the future possible destructions quite often begin to form and develop already in production and assembly stages. The location of such zones is logically stipulated by the construction itself and consequently well known, however now there is no instrument of tracing their fatigue condition until defects appear in them. Thus practical expert examination turns out not to trace the actual condition of metal during the main part of its safe life as there is no opportunity to test fatigue damages accumulation on a microlevel. A reliable diagnostic forecast of serviceability in any stage of safe life with such data incompleteness is naturally impossible. This is confirmed by a great number of breakdowns of different equipment that have often happened just after the regular and quite successful scheduled defectoscopy.

The welded joint is per se a complicated part of construction. Therefore the problem of fatigue condition testing of usual continuous metal is also to the full extent actual in practical weld testing, only with more difficulties. The usual testing system here is focused at first on defects detection of welding proper, and then again on searching weld defects but that occurred in the maintenance process. Between these stages there is a blank in expert examination. It's not a secret that probability of defects detection even in continuous metal, for example, during "hand-operated" ultrasonic testing in maintenance conditions, is on level of 0,5. And for welds this index is not better as defects detection in a weld is worse than in jointless metal. Besides defectoscopy experts seriously insist on that the same expert and same device should always test the same weld. Only such approach to testing, in their opinion, will ensure reliability and reproducibility. The incompleteness of information database for technical diagnosis aggravated with such probability base and subjectivism, does not allow getting a reliable estimation of current condition of jointless metal and weld, as well as metal construction, containing them, as a whole.

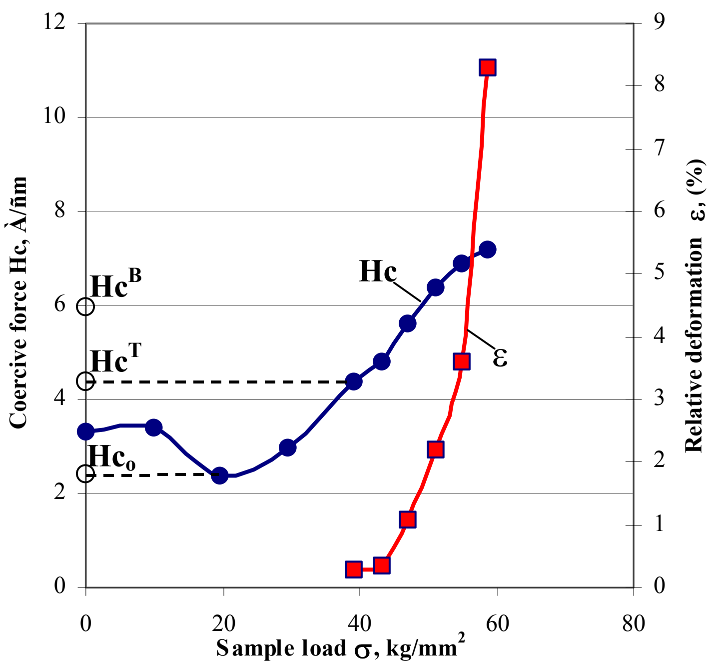
Our long-term experience of technical diagnosis of metal constructions of many types in different branches of engineering convincingly testifies, that such magnetic characteristic of metal as coercive force (Hc) is an effective parameter of testing damages accumulation on a microlevel (i.e. in free of defects for defectoscopy metal). For metalware working in low-cycle fatigue (LCF) condition the Hc value grows from two to three times, from Hc_0 up to Hc^B, while the metal cycles from being new, as supplied, up to the condition of beginning intensive defect formation. And the zones where such fatigue damages accumulation occurs are great, logically predetermined and consequently easily detected. Quantitatively the degree of damage is tested promptly and simply by the value of $Hc_{current}$, more precisely by the degree of measured $Hc_{current}$ value advancement from the initial Hc_0 value to the limiting Hc^B value. With that the estimation does not depend on what expert with what device carries out the measuring. We should note that values of Hc_0 and Hc^B are characteristic constant for each steel quality determined during bench tests, and that absolute majority of equipment inspected by engineering supervision works in LCF condition.

Results: As applied to diagnostics of metal constructions in general the peculiarities of this approach were
expounded in [1].The given paper presents the results received while using coercive force metering in non-destructive testing of metal condition of such a peculiar object as welded joint. A weld of the same type from the moment of equipment production and then during maintenance was being tested. In 10-20 years of operation the occurrence and development of fatigue changes zones were traced, we consequently forecasted occurrence of cracks that would cause emergency stop of equipment. Conducted some time before scheduled defectoscopy did not give any grounds for such development of events in the report. After welding repair of the crack the estimation of welding quality was carried out with coercive force metering by the level of residual stresses and structural heterogeneity of the weld and weld-around zones compared to the parent metal. The weld was monitored on the pipeline of power unit at an A-plant. Working temperature was over 300^0C, pressure – about 160 atm, pipeline diameter – about 1350 mm, wall thickness – 72 mm, 10ГН2МФА steel, width of weld grooving on pipe surface – 100 mm. Peculiarity of the monitored unit does not affect general obtained results. They can be used in fatigue condition monitoring of weld and weld-around zones metal equally or even more successfully in other constructions – from trunk pipeline to such specific pressure vessels as reactor vessel.

The results of weld testing are shown in Fig. 1-A, B, Ca, Cв. Coercive force was measured by magnetic structurescope КРМ-ЦК-2М by setting the transformer of this device onto checkpoint. There were 12 checkpoints on the weld circumference, one for each "hour" of the conventional in pipelines maintenance division of pipe section into testing sectors according to clock dial. And the same number of checkpoints was taken in each of two weld-around zones. Measuring time with the device in one point was no longer than 10 sec. Curvature, roughness and temperature of tested surface do not effect the measuring. As a result of measuring of each given weld we have got a table of Hc values, consisting of 3 lines (one for weld and two for weld-around zones) with 12 Hc values in each line according to the mentioned above 12-hour conventional division. Such table per se presents discrete allocation of Hc values on the surface of tested weld and weld-around zones. (Necessary and sufficient number of checkpoints for the given monitored zone is left beyond this paper). The table contains complete information on the condition of tested weld from coercive force metering point of view. For better obviousness of results presentation a special program of transformation of tabular discrete distribution of coercive force Hc values on weld and weld-around zones into original color continuous distribution was created. Each possible coercive force value from $Hc_o \div Hc^B$ range corresponds to its own color tone, beginning accordingly from dark blue through yellow to red. Thus if geometrical scanning of weld and weld-around zones is given, the layout of this scanning has not numerical values of $Hc_{current}$ in checkpoints but executed coloring of this scanning according to the measured Hc values. Such presentation in color of Hc values allocations on monitored surface is a nonrandom choice. Ours long-term practice of monitoring forming rolls surface after approbation of many variants has proved that just such "color" map of results of surface distribution of Hc is most vivid, promptly and easily understood and accurately "read" by the staff of any qualification. Applied to a weld this way of Hc presentation – monitoring in color has appeared per se just as effective and adequate, since variations of $Hc_{current}$ on a weld are also connected with structural changes, fatigue degradation and residual stresses.

Naturally, the basis of the approach demonstrated in the given paper on estimation of current fatigue condition of a welded joint is primary bench destructive testing of samples. The samples in our case were taken from the pipe made of the same metal quality as the actual welded joints that we had monitored. Samples of two types were prepared. One of them did not contain

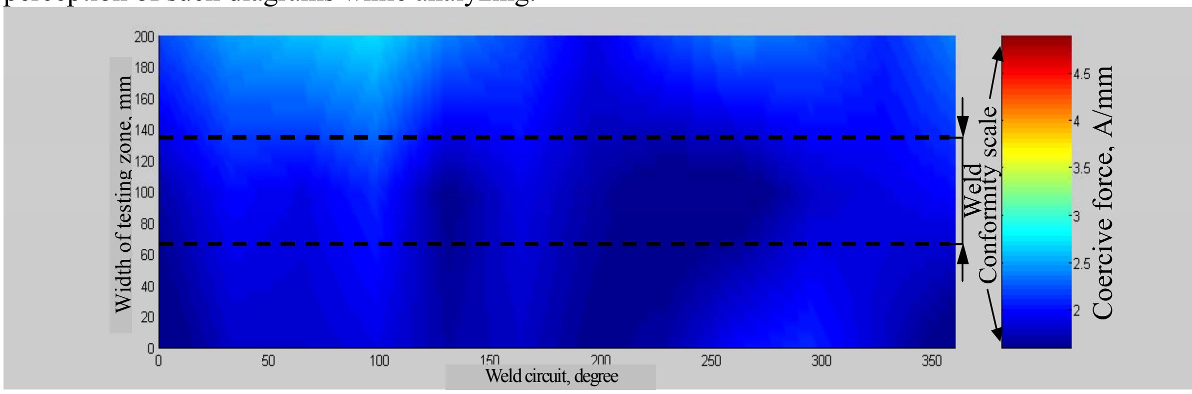
any welds, i.e. was made from the parent metal of the pipe. The other type contained a weld. The samples were put to the bench test by loading with a step increment of tensile load. The coercive force was measured in loaded and unloaded condition after each step of load increase. The graph demonstrates one of those results – bench test of the sample made from the parent metal. As it can be seen these tests allow to determine characteristic points of the diagram of Hc(σ) loading for the given steel quality. They define both the limiting condition of metal Hc_o and Hc^B and important value of coercive force Hc^T relevant to the condition of the tested metal when it is already at the yield point under the effect of all operation factors. This kind of Hc(σ) diagrams are an analogue of diagram of static σ(ε) loading. The dependences Hc(σ) is an original magnetic passport of each steel quality in the tasks of non-destructive testing. They uniquely characterize deflected mode of metal of the given steel quality during operation monitoring of equipment by non-destructive methods. These measurements are especially obvious in the zones of stress concentration. While
analyzing the results of bench tests it is necessary to take into account the difference between the conditions of metal loaded in bench test and in real equipment when the monitoring zone is not in uniaxial planar stressed state but experiences multiaxis volumetric stressing. The limiting values of Hc_o, Hc^T and especially Hc^B in these cases can be different in the samples and in real equipment, which is necessary to take into consideration with corresponding amendments while setting up the tolerance band limits in practical diagnostics.



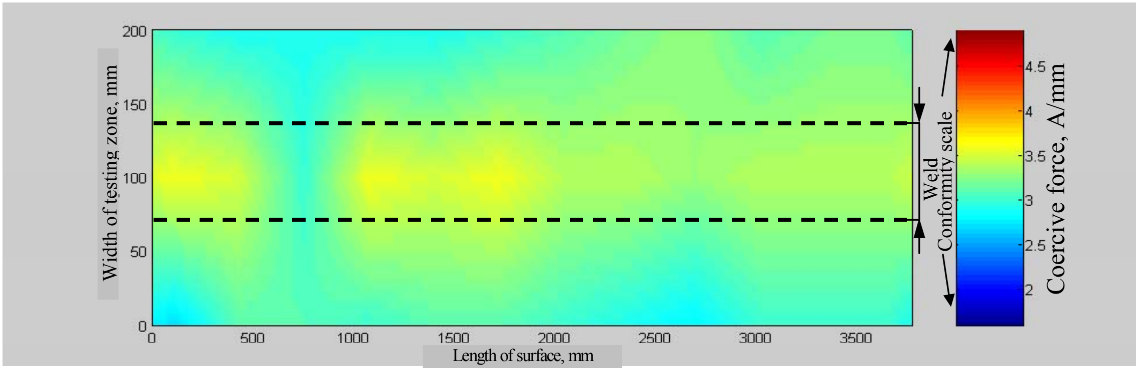
Testing of sample made from 10ÃÍ 2Ì ÔÀ steel.

Discussion: Fig. 1-A shows a new weld welded in the conditions of manufacturing plant. The equipment containing this welded joint is not installed in the block and is kept in a storehouse. A similar weld on another unit – part of a power unit having been in operation for 20 year – is shown in fig. 1-B. A similar weld on a unit of the same type but with 12 years' service life in the same power unit is shown in fig. 1-C_a. The same weld, only one year later is shown in fig. 1-$C_в$ already in the condition after the unit's stop caused by a crack occurred in this weld.

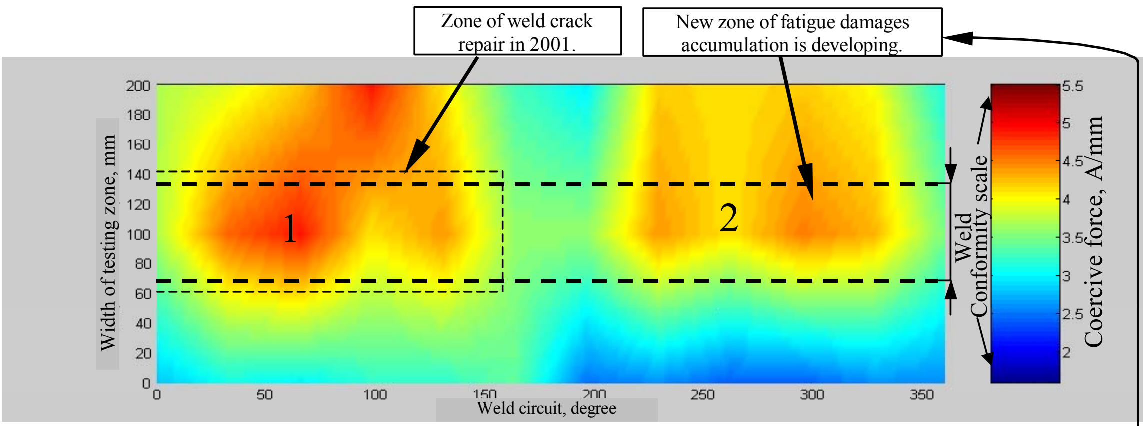
The right-hand part of each figure demonstrates a vertical color scale defining which Hc value matches the given color of tested zone of the monitored weld. A simple and clear principle “the more red, the worse” used here ensures practically error-free and psychologically correct perception of such diagrams while analyzing.



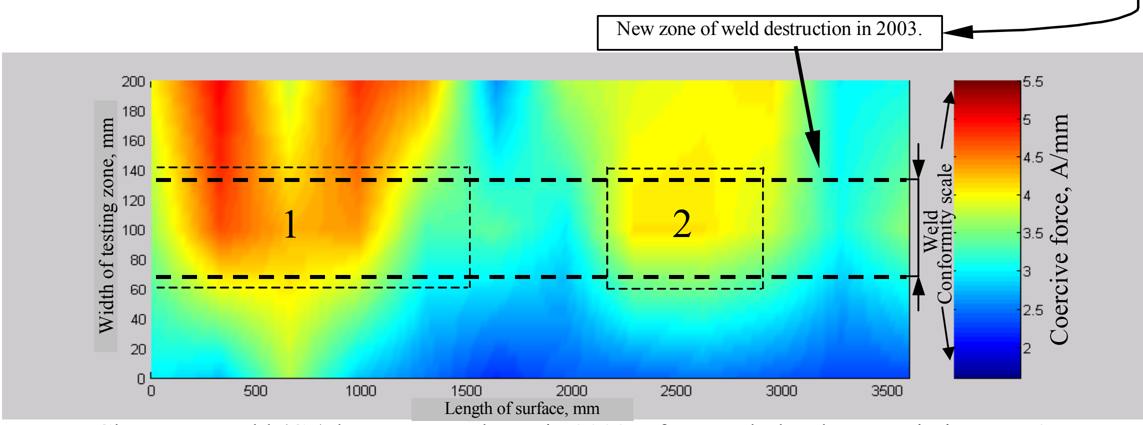
A – weld on a new uninstalled steam generator



B – similar weld on a unit been in operation for 20 years



Ca – similar weld on another unit in its twelfth year of operation, year 2002.



Cb – same weld (Ca) but one year later, in 2003, after crack development in its zone 2.

Fig. 1. Fatigue condition testing of welds by measurements of metal coercive force in all stages of its safe life.

Fig. 1 clearly shows the possible limiting stages of metal condition in welded joint zones in operation. Weld in a fig. 1 was tested by coercive force metering on a new not working and not installed unit. The values of coercive force of metal of the weld and weld-around zones practically do not differ, as well as they do not differ on all circumference of the welded joint. That is the weld is homogeneous itself, and as compared with its both weld-around zones. There are no residual stresses and structural heterogeneities of metal here.

Fig. 1-B demonstrated a similar weld only on a unit already been in operation for 20 years. Having

analyzed its coercive force metering we can conclude, that this weld on the manufacturing plant was made of high quality, as well as weld in fig. 1. The installation of the unit into the power unit did not cause any changes in the weld, as the influence of constructional loads on metal condition in this joint is not scanned. The working loads of temperature and pressure have caused the normal inevitable natural uniform shift of $Hc_{current}$ values by $\Delta Hc \approx 1$A/cm in this weld from the initial, starting condition $Hc_0 \approx 1{,}5 \div 2$ A/cm. Here the zone of the weld itself already clearly stands out against a background of weld-around metal. On the whole this welded joint is adequate to its service life, all its zones are in the area of resiliencies. Here the presence of fatigue defects, as well as developing defects of welding or metallurgical origin are improbable.

Fig.1-C shows a similar weld with 12 years' service life twice, with one-year interval. Fig. 1-Ca is the result of the weld testing in 2002 during the scheduled routine maintenance. Serviceability of the weld by the results of the conducted defectoscopy is to be faultless. From the point of view of coercive force metering it is far from being so. In zone 1 of this weld a year before there had been done repair work with sampling and welding caused by a through crack. It is obvious, that in this zone even if it has no defects (which is rather doubtfully; most likely they could not be detected) metal is already in the area of plastic deformations. And if there are truly no defects here, their occurrence is the matter of the nearest future. The transient behavior itself during putting the unit in operation can easily provoke the mechanism of conversion of accumulated in zone 1 fatigue microdamages of metal into microdamages-cracks. (Let's leave the question, why so soon after the repair this weld zone turned out to be in breaking point, beyond the given paper). With all unsatisfactory condition of zone 1 of this weld, near it there developed as dangerous zone 2 that also had not been traced at all by defectoscopy testing. We can say all the same negative things about it as about zone 1 with only one difference that this zone had not been repaired before. The most probable reason of such condition of this weld is high level of stresses in the construction of supply pipeline in which this weld "works". Such poor-quality mounting could be complicated by poor initial execution of the weld at the manufacturing plant. These two complicating factors could coincide and mutually aggravate each other.

Here it is necessary to note, that according to the standards operating in CIS, the equipment that in zones of stresses concentration has metal in such condition, as in zones 1 and 2 shown in fig.1-C, cannot be put in operation by the results of its technical diagnosis based on magnetic characteristics (according to standard ГОСТ 30415-96).

In fig 1-Cв the same weld is shown, when almost in year of operation the power unit was stopped because of developed in zone 2 crack. It is clearly seen here, that zone 2 looks more safely than a year before in fig. 1-Ca. That is the way it should be as the stresses accumulated in this zone, which are so well indicated by coercive force metering in fig. 1-Ca, relaxed having created that very emergency crack. And the analyses of zone 1 in these two figures shows that the degradation in it during the last year has essentially progressed both in growth of absolute Hc values and degree of abnormal propagation of this zone on surrounding weld zones and especially on weld-around zone. Probability of fatigue defects presence in zone 1 is practically unitary. It would be more logical not to wait for them and to not search them but to execute preventive repair.

Conclusions: 1. Thus coercive force metering has traced main welded joint states – from new, as supplied, to destruction as a through fatigue crack. The value of coercive force relevant to these limiting conditions of metal differs by three times. None of the known parameters of nondestructive testing has such high sensitivity to fatigue condition moreover in combination with repeatability independently of type and location of equipment. The measurements of Hc value are easily taken in practice by ordinary staff with minimum training. The device – magnetic structurescope from КРМ-Ц series – is simple and compact, has been already working in workshop and field conditions for over ten years.

2. Applied to a welded joint coercive force metering allows evaluating quality of a just welded weld and its parts by the level of residual stresses and structural heterogeneity of metal.

Against this background it is also easy to track the quality of mounting of metal constructions containing the monitored weld since comparative coercive force metering of a weld before and after mounting clearly demonstrates presence/absence of ΔHc growth because of assembly stresses in the construction.

3. Systematic coercive force metering of a weld while in service does not require any special expenditures of time and finance and allows organizing database on each weld, tracing the origin, development and accumulation of fatigue zones, which cannot be done by any other mass method of nondestructive testing now. All these have created the necessary prerequisites for transition in maintenance from universal search of defects to their prevention, as well as to prevention of emergency. It can become a normal working practice of an expert and basic actual contents of diagnostics today.

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