PRZEWODNIK METODYCZNY DLA PRZEPROWADZENIA INSPEKCJI JEDNOSTEK ZASILAJĄCYCH LOKOMOTYWY ELEKTRYCZNE Z ZASTOSOWANIEM METALOWO MAGNETYCZNEJ PAMIĘCI

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Streszczenie:

Niezawodność jednostek napędowych lokomotyw elektrycznych jest jednym z najważniejszych warunków bezawaryjnej pracy kół napędowych lokomotyw. W obecnych czasach, pomiary optyczne oraz metody kontroli oparte o cząstki magnetyczne są podstawowymi metodami badania jednostek napędowych lokomotyw elektrycznych, w szczególności stosowane dla reguł naprawczych lokomotyw elektrycznych „CS". Metoda metalowo – magnetycznej pamięci jest efektywną metodą dla szacowania stanu naprężeniowo – odkształceniowego obiektów, która staje sie coraz szerzej i częściej stosowaną w praktyce. Metoda ta jest nie – niszczącą metodą, opierającą się na rejestracji i analizie rozprzestrzeniania się pól magnetycznych po powierzchni obiektu w celu ustalenia stref koncentracji naprężeń, defektów i niejednorodności metalowych i zespawanych konstrukcji.

Słowa kluczowe: niezawodność, jednostki napędowe lokomotyw elektrycznych, metalowo magnetyczna pamięć

METHODICAL GUIDELINE FOR INSPECTION OF ELECTRIC LOCOMOTIVE POWER UNITS (FROG, SHAFT AND SPLINE JOINTS) USING THE METAL MAGNETIC MEMORY

Summary:

Reliability of electric locomotive power units is the most important condition of electric locomotive wheel gear trouble-free operation. At present visual-measuring inspection and the magnetic-particle method are the basic methods of electric locomotive power units inspection according to the "CS" electric locomotive Repair Rules. The method of Metal Magnetic Memory is an effective method for equipment stress-strained state assessment, which becomes more and more widely spread in practice. MMM is a non-destructive testing method based on registration and analysis of self-magnetic leakage fields distribution on products surface for determination of stress concentration zones, defects, metal and welded joints structure inhomogeneity.

Keywords: reliability, electric locomotive power unit, metal magnetic memory

1. GENERAL

Reliability of electric locomotive power units (including frogs, shafts and spline joints) is the most important condition of electric locomotive wheel gear trouble-free operation.

The problem of unexpected electric locomotive power units fatigue failures cannot be solved using traditional non-destructive testing methods (UT, MPI, eddy-current method, etc.) since they are oriented to detecting the already developed defects, which is insufficient for providing their reliability. Besides, inspection of complex-shape units using the traditional NDT methods is impossible in a number of cases and requires large effort.

At present visual-measuring inspection and the magnetic-particle method are the basic methods of electric locomotive power units inspection according to the "CS" electric locomotive Repair Rules (CT/4015).

Mechanical stress concentration zones are the main sources of units damaging, in which corrosion and fatigue processes flow the most intensively. Units damaging occurs, as a rule, unexpectedly and are of fatigue nature. Thus, for timely detection of susceptible to damaging units, methods of engineering diagnostics having correlation with mechanical stresses are required.

The method of Metal Magnetic Memory (MMM) is an effective method for equipment stress-strained state assessment, which becomes more and more widely spread in practice.

According to GOST R 52081-2003 the metal magnetic memory (MMM) is an aftereffect, which becomes apparent in the form of residual magnetization of products and welded joints metal formed in the course of their fabrication and cooling in a weak magnetic field or in the form of irreversible changing of products magnetization in stress concentration and damaging zones due to working loads.

MMM is a non-destructive testing method based on registration and analysis of self-magnetic leakage fields (SMLF) distribution on products surface for determination of stress concentration zones (SCZs), defects, metal and welded joints structure inhomogeneity.

SMLF is a magnetic leakage field occurring on the product surface in the zones of dislocations stable slipbands under the influence of operational or residual stresses and in zones of maximum inhomogeneity of metal structure.

All units have in the initial state the residual magnetization formed naturally at their fabrication. In conditions of operation this magnetization changes and re-distributes under the influence of working loads.

Under the action of vibration processes, torque and bending moments as well as of tensile-compression forces occurring in parts and units at electric locomotive motion, an appropriate stress field forms in shear plane with the maximum metal strain in weakened part sections. Stable dislocation slipbands and glide pads occur in the same area on parts surface long before reaching the metal yield strength. The moment of stable dislocation slipbands occurrence is related to internal stresses (tensile and compression stresses) level and direction. Stable dislocation slipbands, occurring under the influence of cyclic loads repeating in the same place, may develop to channels with dimensions up to tens and hundreds of microns by depth and width, which will be already notable at the macrolevel. Plastic strain develops and, finally, cracks initiate along these channels boundaries. By virtue of the magnetomechanical effect SMLF with an appropriate orientation and, as a rule, with sign alternation occurs on the part section surface, where stable dislocation slipbands have formed.

The many-years experience in investigation of magnetic fields distribution on various types of equipment revealed presence of stable sign alternation lines of the H_p magnetic field normal component or its abrupt local variation in SCZs being the sources of metal damaging development. The same local variations of the H_p field were revealed in the course of special industrial experiments on many inspected electric locomotive power units.

For quantitative assessment of stress concentration level the gradient (variation intensity) of the H_p magnetic field normal and (or) tangential component in SCZs is determined:

$$K_{in} = \frac{\left|\Delta H_p\right|}{\Delta x},$$

where K_{in} – is the magnetic leakage field gradient or the stress intensity magnetic factor characterized by metal magnetization variation intensity in SCZs and, accordingly, by the H_p field variation intensity; $|\Delta H_p|$ - is the modulus of the H_p field difference between the two adjacent inspection points located on identical sections Δx. At using a PC-based instrument the field gradient *(dH_p/dx)* is determined automatically.

<u>Basic advantages of the MMM method:</u>

- application of special magnetizing devices is note required as the phenomenon of units magnetization in the process of their operation is used;
- locations of stress concentrations are unknown beforehand and are determined in the course of inspection;
- metal dressing or any other preparation of the test surface is not required;
- small-sized instruments, self-contained power supply and recording systems are used to perform inspection by the proposed method.

The main task of the MMM method is detecting of SCZs – the anomalous magnetic leakage field zones – on the inspected units surface. Then, using a specialized program "MMM-System", parts sorting by the degree of their susceptibility to damaging in SCZs is carried out. Parts screening and sorting may be done directly at inspection by K_{in} values corresponding to a specific part metal pre-failure limiting state. K_{in} value corresponding to metal limiting state is determined in the course of experimental investigations separately for each part.

For timely detecting parts and units with the maximum stress concentration as well as for carrying out non-destructive testing prior to their installation on an electric locomotive, it is recommended to apply the metal magnetic memory method. This methodical guideline is developed for inspection of the most damageable units of railway motors (frog, shaft, spline joints). Limiting values of K_{in} for the listed above parts and units were determined in the course of experimental works at "Moscow-Sortirovochnaya" depot and at Yaroslavl Repair Plant.

The considered magnetic method of electric locomotive power units diagnostics may be used both independently and (or) in combination with other destructive and non-destructive testing methods. According to this MG it is not recommended to apply the magnetic-particle method with artificial magnetization at parts inspection.

2. DESIGNATION AND APPLICATION SCOPE

2.1. This methodical guideline (MG) specifies the procedure of electric locomotive power units (frog, shaft, spline joints) inspection using the MMM method both as an independent type of inspection and in combination with other non-destructive testing (NDT) methods.

2.2. This MG may be applied for sorting of new and used parts and units by their susceptibility to damaging.

2.3. This MG covers power parts and units of this family (or model) electric locomotives and may be applied at quality inspection of electric locomotive power parts and units of other families with corrective changing of quantitative criteria of metal limiting state to another standard size of parts and steel grade, of which they are fabricated.

2.4. This MG is based on SMLF recording along parts surface in the areas of their most probable damaging. SMLF characterize metal residual magnetization distribution formed under the influence of working and residual stresses.

2.5. This MG allow:

- detecting new parts with metal defects and areas of inadmissibly high residual stress concentration;
- carrying out parts sorting at their repairs and detecting parts operating in the most stressed conditions and susceptible to damaging (or already damaged);
- detecting part sections (new and used) with the maximum stress concentration and timely performing their repairs using grinding and various strengthening and recovery technologies;
- reducing the scope of inspection and parts replacement.

2.6. The MMM method is primary relative to other NDT methods. Upon detecting SCZs by the MMM method, part surface grinding is carried out in these zones and a visual-measuring inspection is performed. To detect cracks presence in SCZs it is feasible to used an eddy-current inspection or colour flaw detection.

3. INSPECTION INSTRUMENTS AND THIR OPERATING PRINCIPLE

3.1. Table 1 gives characteristics of instruments used at inspection by the MMM method.

3.2. To measure the magnetic leakage field intensity along the pipeline surface TSCM-2FM and TSC-1M instruments with flux-gate converters are used. Field meters or gradiometers can be used as sensors for these instruments.

3.3. The operating principle and conditions of a specialized TSC-2FM-type magnetometer equipped with a flux-gate converter with the magnetic field (H_p) intensity-measuring sensor are given in the instrument's passport. This instrument is designed for inspection of small-diameter parts and units.

3.4. To improve inspection effectiveness and speed a TSC-1M-type instrument (tester of stress concentration) is used. The instrument is equipped with special scanning devices incorporating a length-measuring sensor, two or more flux-gate converters for the magnetic field intensity measuring along the part surface. Appendix 1 gives the description of the TSC-1M instrument and the specialized sensors. Besides, the instrument has a lighted screen for displaying the graphical information, permanent memory and the program for automatic processing of the H_p field measurement results by pre-specified criteria. The detailed description of the instrument, its operating principle and operating manual are given in the technical passport.

3.5. TSC-2FM and TSC-1M instruments are adjusted for the H_p magnetic field intensity measurement (A/m) on a reference coil certified in Rosstandard.

The error of the H_p field measurements at inspection of a part with undressed surface does not exceed 5%.

Application of this technique is most effective on condition that the inspection object's surface is not dressed to metallic luster and there is no artificial magnetization (for instance, after the magnetic-particle inspection).

3.6. The EMIC-1-type instrument (electromagnetic indicator of cracks) is used for detecting surface cracks presence in SCZs. The instrument is applied, first of all, for detecting of cracks in stress concentration zones. And weld surface dressing is not required. The EMIC-1 instrument operating principle description is given in the technical passport..

4. INSPECTION TECHNIQUE

4.1. Preparation for inspection.

Parts inspection is carried out in finished-product workshops at manufacturing plants or at depot at their repairs. Metal dressing is not required to provide SMLF measurements on parts surface. Oils and dirt should be removed from parts surface.

At inspection by the MMM method parts should not contact each other. It is recommended to locate parts of the same type in the same position isolated from metallic products and structures. It is better to locate them on wooden tables or decks. Each part is inspected separately using the required devices and specialized sensors. Type of sensors is given in the description of the inspection technique for each part.

Two specialists carry out inspection. One of them performs scanning with the instrument sensor along the part surface. Another specialist (assistant) helps in parts preparation for inspection and makes records and notes in the part log or logbook, makes the necessary marks with chalk or paint directly on the part surface in the course of inspection.

At appropriate conditions (small pipeline dimensions, large experience of an operator in MMM inspection) inspection may be carried out by one operator provided the safety rules are observed.

4.2. The technique for frogs inspection.

4.2.1. Inspection of used frogs.

Surfaces on both sides and pivots filler junctions are inspected on frogs. Fig. 1 shows the scheme of a frog surface inspection using Type 2 and Type 3 sensors allowing simultaneous measurement by three measurement channels. Fig.1 shows the direction of scanning at inspection with arrows.

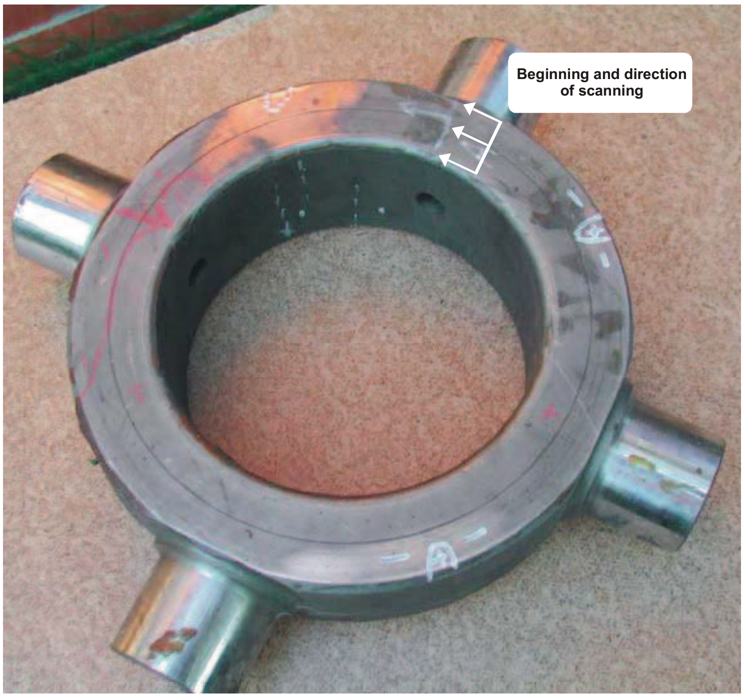


Fig. 1. Scheme of frogs surface inspection using a specialized three-channel sensor

Measurement of the H_p magnetic field normal component simultaneously by three circumferences along the entire perimeter (internal, mean and external frog diameter) is carried out on frogs surface. At inspection zones with the maximum value of the H_p field and its gradient (dH_p/dx) along each measurement channel are recorded. These zones are marked with paint or special soft-tip pen on the frog surface. Inspection is repeated in a similar way on the opposite side of the frog.

Frogs, on which field gradient values of $dH_p/dx \geq 150 \div 200 \times 10^3 (A/m^2)$ were recorded on butt-ends surface at inspection, are marked with a special symbol, sorted separately and referred to the group of frogs subject to repairs. Frogs, on which field gradient values of $dH_p/dx \leq 150 \times 10^3$ (A/m^2) were recorded on butt-ends surface at inspection, are referred to the group of frogs with satisfactory butt-ends surface state and may be admitted to further operation.

Fig.2 shows the scheme of fillet junctions inspection on frog pivots using specialized sensors. A specialized sensor incorporates flux-gate two-component converters 1 for simultaneous measuring of the magnetic field normal and tangential components and an annular device 2 for scanning along the perimeter of the pivot fillet junction.

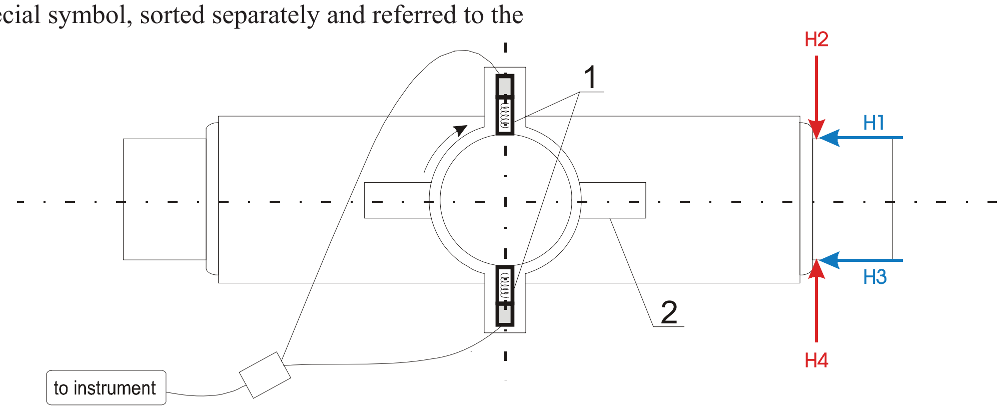


Fig. 2. Scheme of fillet junctions inspection on frog pivots using a specialized sensor
1 – flux-gate converters;
2 – device for scanning along a fillet junction perimeter

Scanning at inspection is carried out in the “timer” mode set on the TSC-1M instrument by turning the annular device by 180 degrees relative to the beginning (reference point) of scanning marked prior to inspection with a special symbol directly on the fillet. One flux-gate converter performs measurement of the magnetic field along the first half of the fillet perimeter, and another converter performs measurement along the second half of the fillet. The annular scanning device in combination with two flux-gate sensors allows carrying out inspection simultaneously along the entire pivot fillet perimeter.

For the sake of convenience of all pivot fillet junctions alternate inspection it is recommended to install the frog on a wooden shaft or a wooden support (see Fig.3).

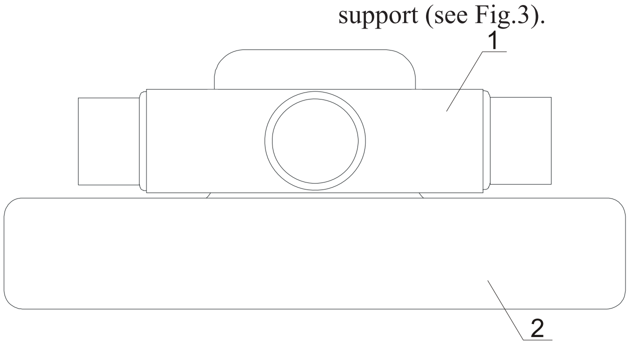


Fig. 3. Wooden support for frogs inspection by the MMM method
1 – frog;
2 – wooden support for inspection.

At inspection zones with the maximum field and its gradient *(dH_p/dx)* value along each measurement channel (4 channels in total, two of them measure the normal field component, and two – the tangential field component) are recorded. Frog pivots, on which field gradient values of $dH_p/dx \geq 70 \div 100 \times 10^3 (A/m^2)$ were recorded at inspection along any measurement channel, are marked with paint, and this frog is referred to the group subject to repairs.

Frogs, on which field gradient values of less than $70 \times 10^3 (A/m^2)$ were recorded at inspection of pivot fillet junctions, are referred to the group of frogs with satisfactory pivots state and may be admitted to further operation.

Fig.4 shows the example of a used frog surface inspection results with the field gradient value in some areas of greater than $200 \times 10^3 (A/m^2)$. Photo 1 shows stress concentration lines corresponding to the H_p magnetic field sign alternation lines, detected at inspection, and Photo 2 shows a microcrack detected using the chip in the area of the maximum field gradient value with magnification x100. Fig.5 shows the examples of pivot fillet junctions inspection results with field gradient values of greater than $100 \times 10^3 (A/m^2)$.

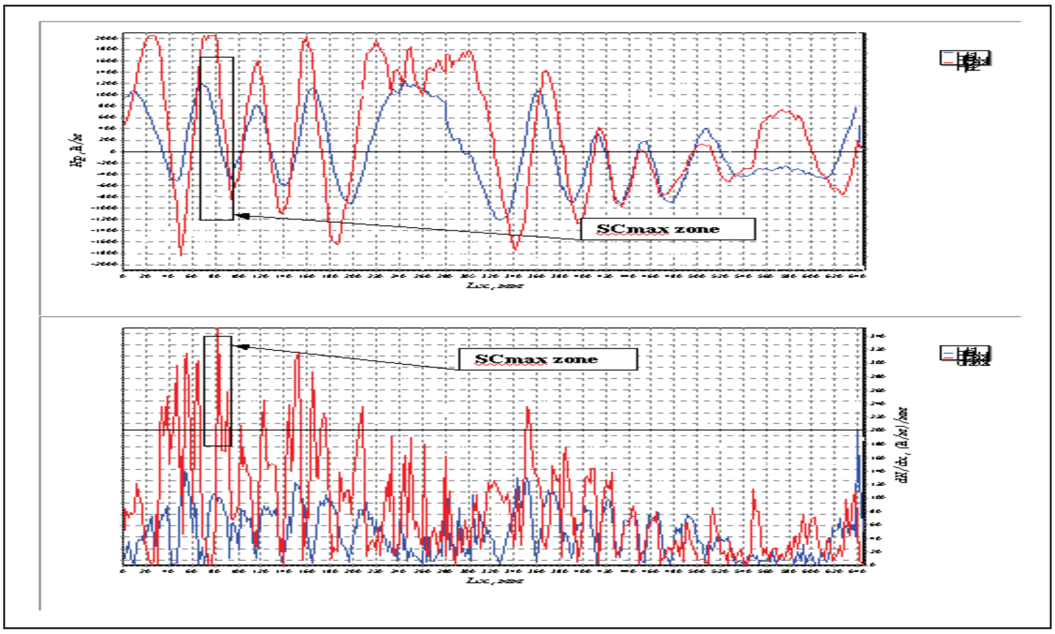
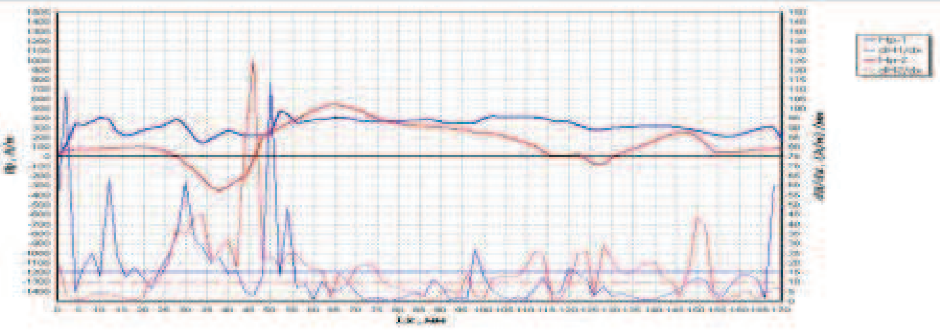
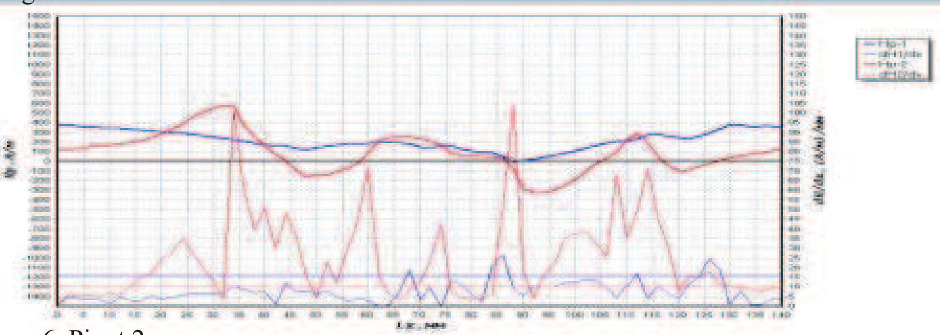


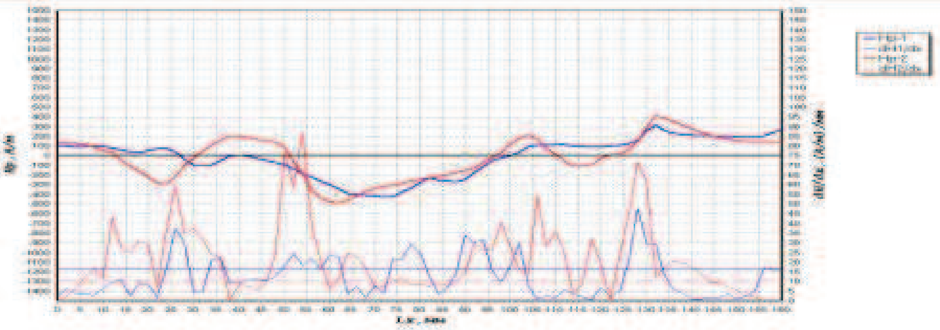
Fig. 4 Distribution of the H_p field and intensity factor *dH/dx* on the surface of frog # 6 (side A)
Frog 6. Side A. External diameter



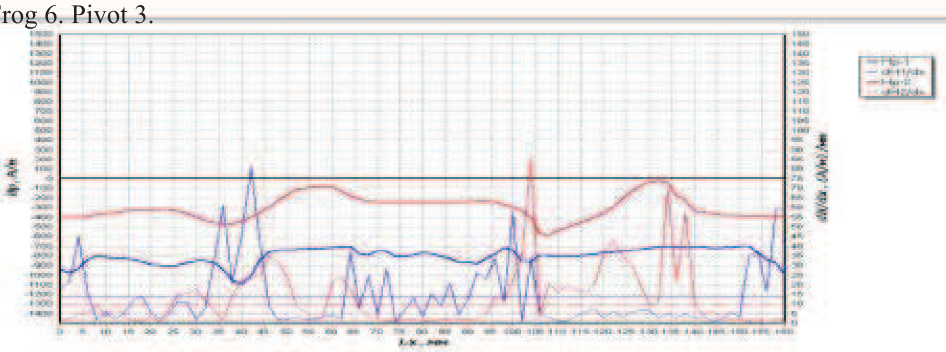
Frog 6. Pivot 1.



Frog 6. Pivot 2.

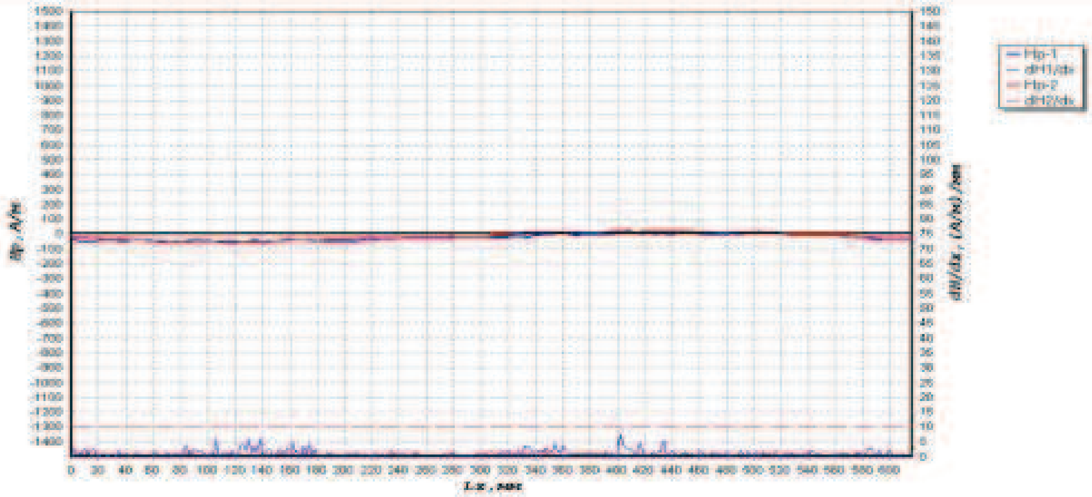


Frog 6. Pivot 3.

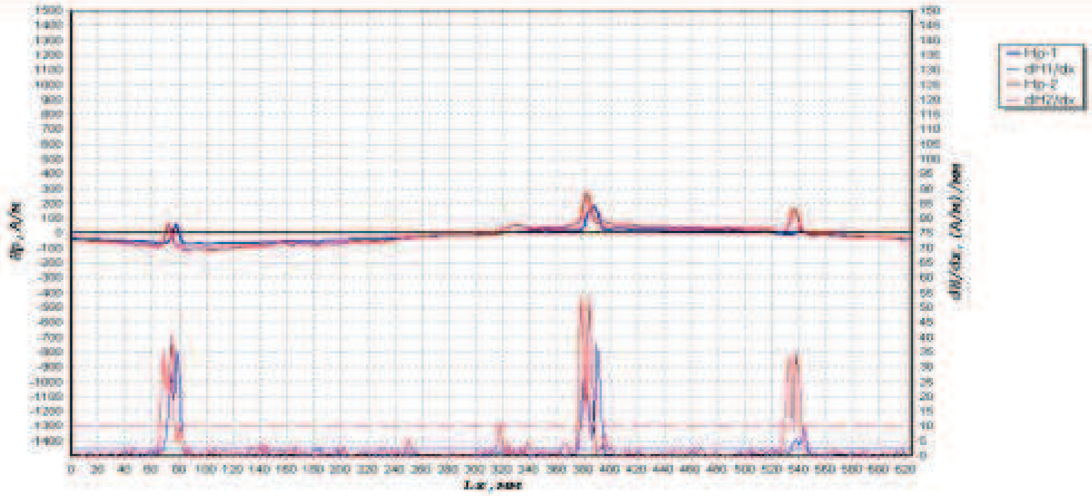


Frog 6. Pivot 4.

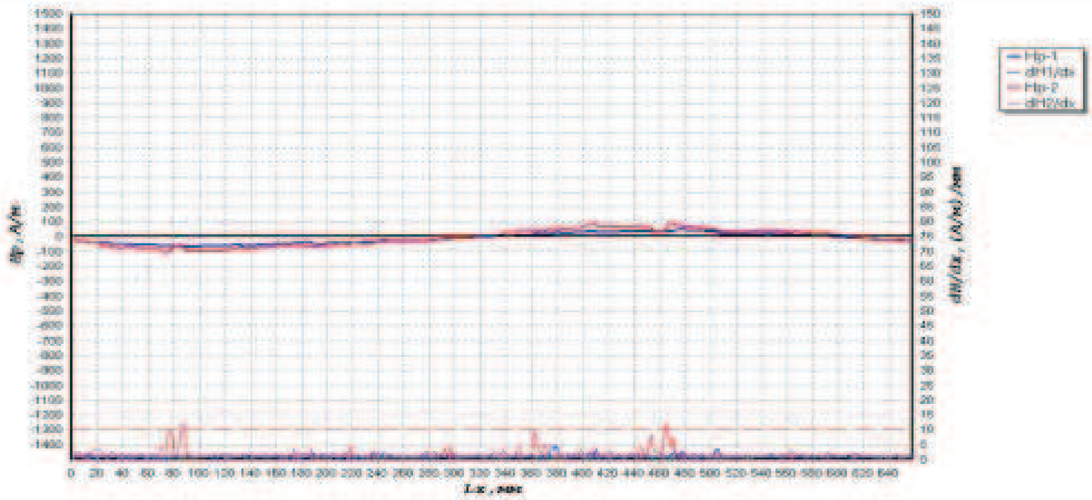
Fig. 5. Results of frog #6 pivots inspection



New frog 43. Side A. Internal diameter.



New frog 43. Side A. External diameter.



New frog 43. Side A. External diameter. After grinding.

Fig. 6. Results of inspection along external and internal diameters
of a new frog # 43

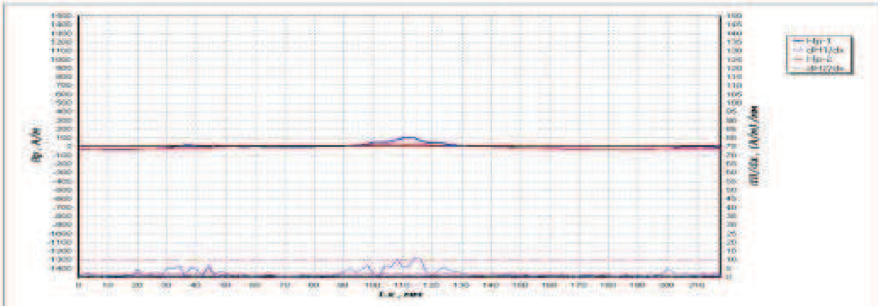
4.2.2. Inspection of new frogs.

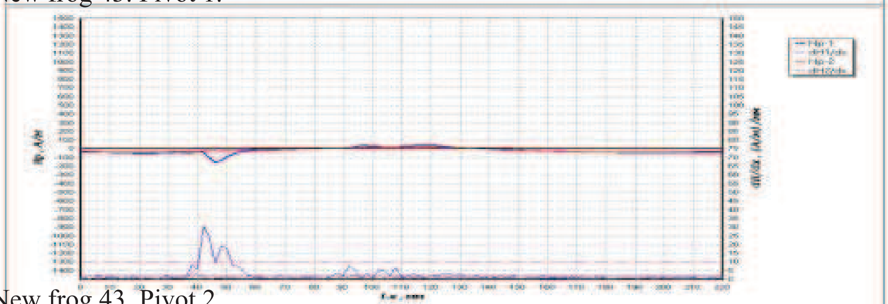
New frogs inspection is carried out in a similar way according to inspection schemes shown in Fig.1 and Fig.2. The main task of new frogs inspection is detecting of maximum residual stress concentration zones determined by the process of their fabrication.

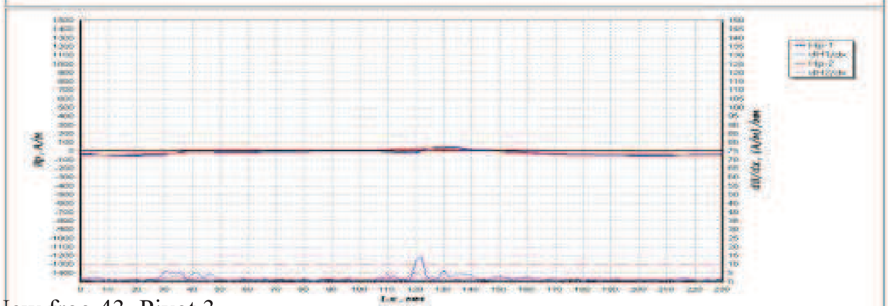
Frogs, on which field gradient dH_p/dx values of greater than 30×10^3 *(A/m²)* were recorded at inspection on the butt-ends surface and with the field gradient values of greater than 10×10^3 *(A/m²)* on pivot fillet junctions, are subject to grinding in these areas with re-inspection by the MMM method.

New frogs, on which areas with field gradients below the reported values were detected by the MMM method, may be admitted for operation.

Fig.6 and 7 present examples of inspection results of pivots surface and fillet junctions on new frogs respectively. Areas of the H_p magnetic field local surges recorded on the frog surface 43 (see Fig.6) correspond to stress concentration (SC) zones on the structure inhomogeneity.


New frog 43. Pivot 1.


New frog 43. Pivot 2.


New frog 43. Pivot 3.

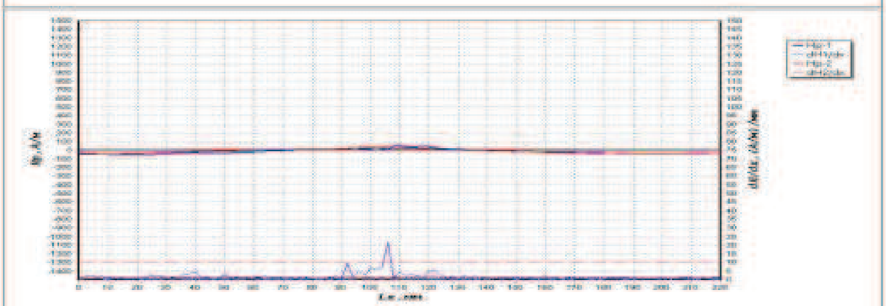

New frog 43. Pivot 4.

Fig. 7. Results of a new frog #43 pivots inspection

Photo 3 shows SC zones detected on the Frog #43 surface at inspection along the external diameter.

At additional inspection with a "TEMP-3"-Type (CNIITMASH) hardness meter an increased hardness of 500-550 HB was revealed in a SC zone. The average frogs surface hardness outside SC zones was 450-480 HB. It should be noted that the average hardness of side frog surfaces is about 600 HB.

4.3. The technique for drive shafts inspection

Three sections in spline zones, a spline junction and four generatrixes along the shaft with bias by 90° relative to each other are inspected at drive shafts repairs. Shafts inspection by the MMM method is carried out directly after the visual-tool examination. Fig.8 shows the scheme of a drive shaft inspection using a two-channel sensor (Type 2). The direction of scanning at inspection is indicated with arrows in Fig.8. At inspection in these units zones with the maximum values of the H_p field and its gradient (dH_p/dx) along each measurement channel. These zones are marked with paint or special soft-tip pen on the surface. Shafts, on which field gradient values of $dH_p/dx \geq 10 \div 20 \times 10^3$ (A/m^2) were recorded at inspection on any of the indicated in Fig.8 units, are marked with a special symbol, sorted separately and referred to the shaft group subject to repairs.

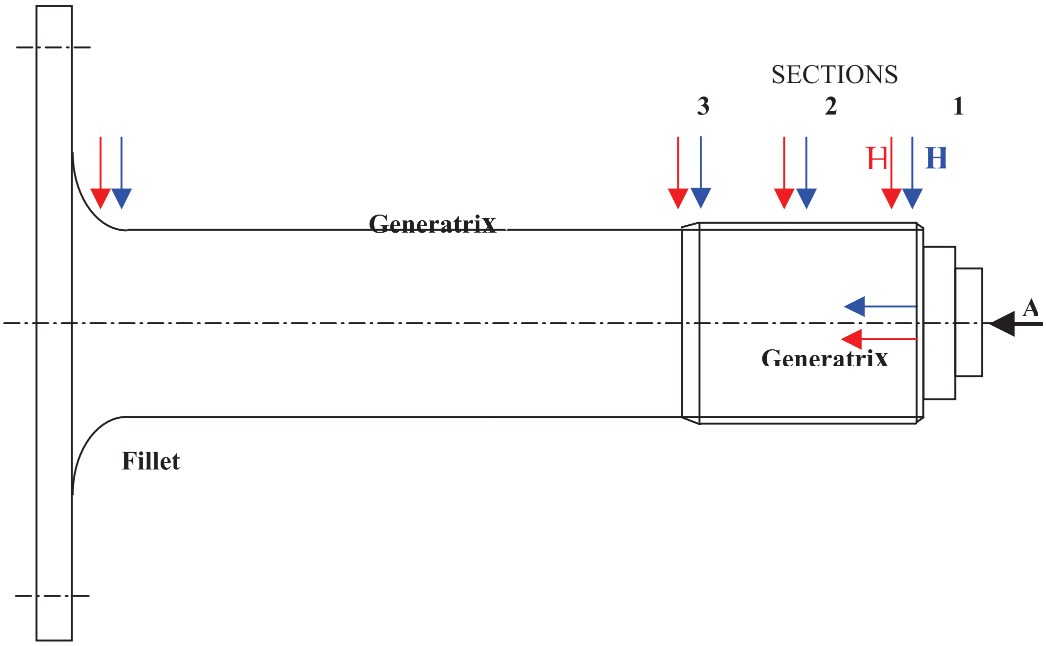


Fig. 8. Scheme of shaft sections inspection by the metal magnetic memory method.

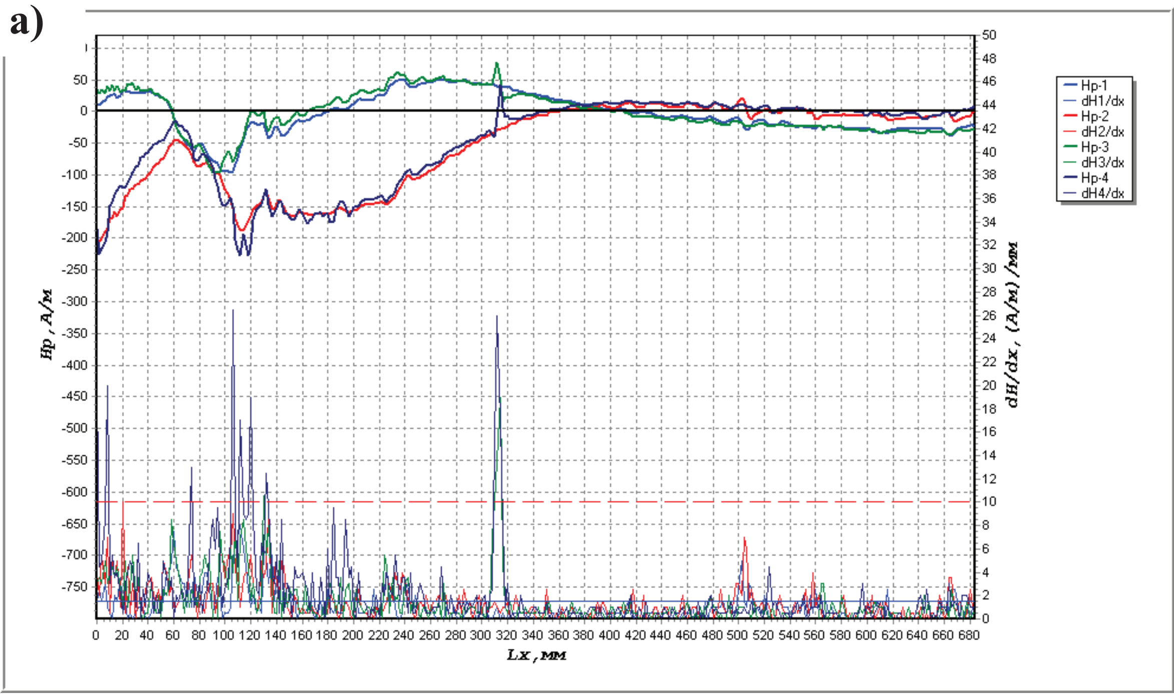
It is recommended to perform metal surface grinding and to repeat inspection on these shafts in SC zones detected by the MMM method. Grinding should be carried out before the time the magnetic anomalies disappear in SC zones. If after grinding in SC zones geometrical shaft dimensions are within acceptable limits, such shafts may be admitted for further operation.

Shafts, on which maximum field gradient values of $dH_p/dx \leq 10 \times 10^3$ (A/m^2) were recorded at inspection in SC zones, are referred to the group of shafts with satisfactory state and may be admitted to further operation.

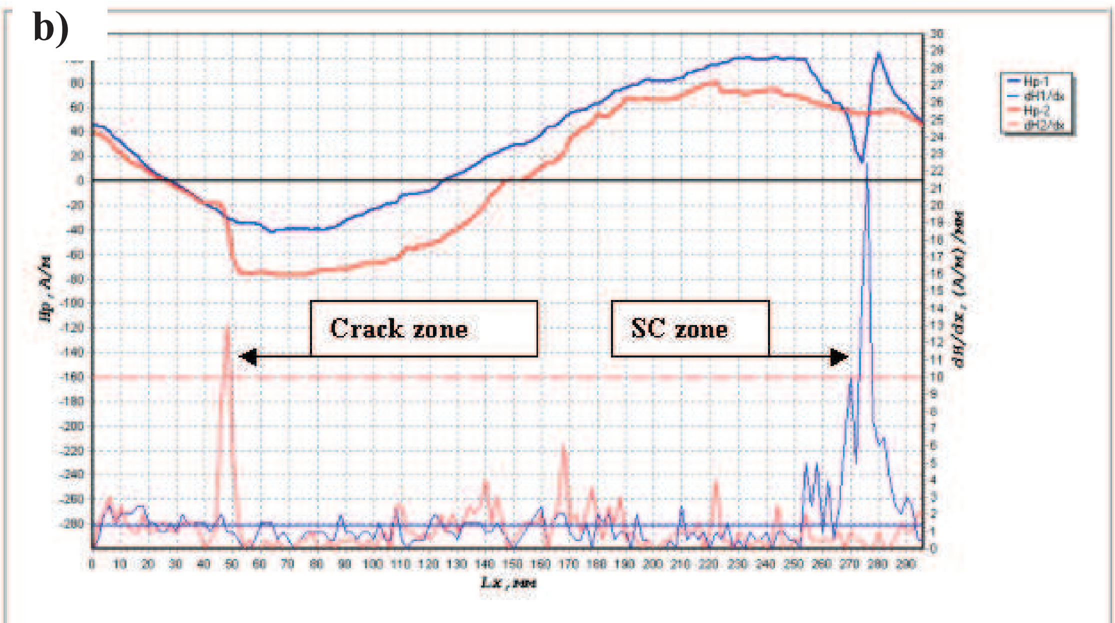
Note: On shafts with artificial magnetization (the H_p magnetic field on the shaft butt-end is greater than 1000 *A/m*) the acceptable values of the field gradient (dH_p/dx) are, as a rule, large. The limiting values of the field gradient for such shafts are established experimentally based on the inspection results statistics set.

Fig.9*a* shows inspection results by the MMM method of a drive shaft with a satisfactory state in section 3. Fig.9*b* shows the shaft inspection results with crack propagation starting in section 3, in the area of transition from splines to the shaft base metal. It is seen in Fig.9*b* that in the propagating crack area the field gradient value approaches 13×10^3 (A/m^2). And a SC zones with the field gradient value of 23×10^3 (A/m^2) was detected at a distance of ~210 mm along the shaft perimeter in section 3. At lengthwise scanning along the two diametrically opposite shaft generatrixes SC zones with the field gradient value of 26×10^3 (A/m^2) were detected on this shaft at a distance of 310 мм from the end (see Fig.*10a*). At lengthwise shaft scanning, i.e. perpendicular to the crack, the field gradient value in the crack zone approaches $28 \times 10^3 (A/m^2)$.

This shaft cannot be admitted for further operation and is subject to replacement.



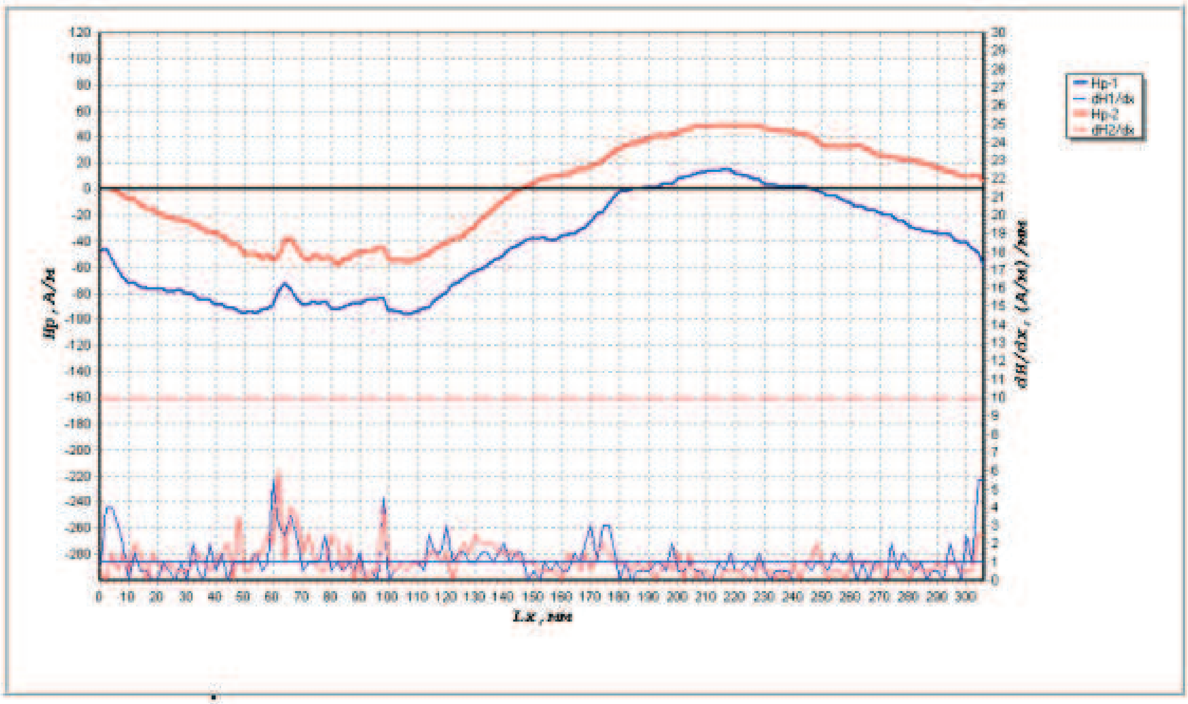
H_p field distribution along the shaft generatrix.



Shaft 1. Section 3.

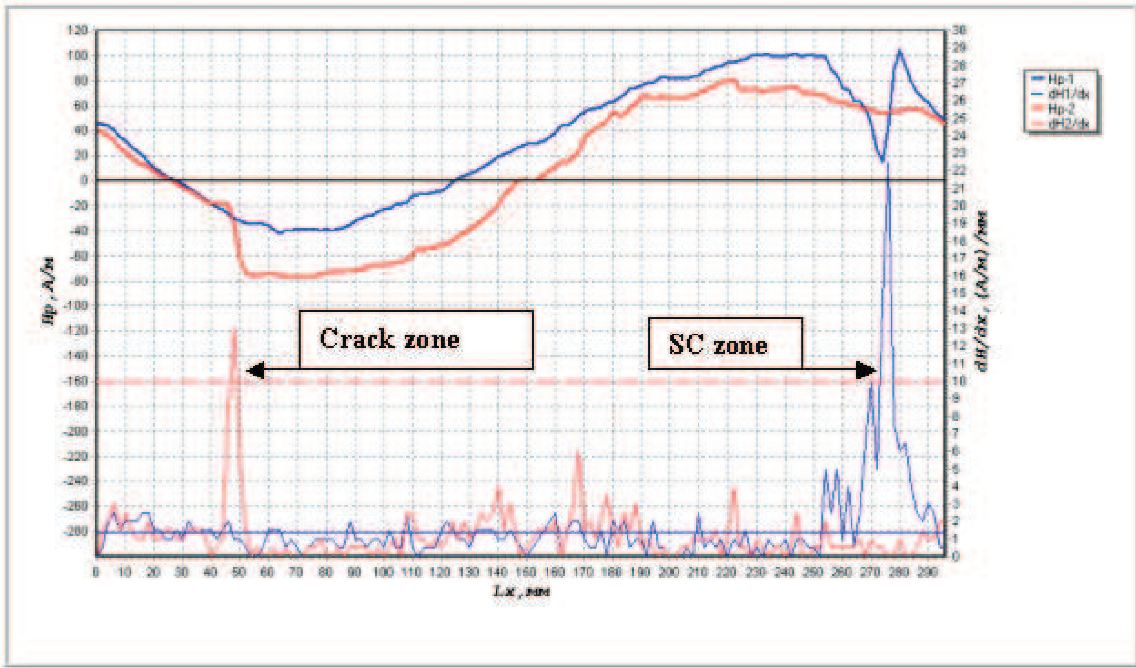
H_p field distribution in the section 3 of the shaft

Fig. 10. Results of inspection by the MMM method of a shaft with a developing crack



Shaft 5. Section 3.

Fig. 9*a* Results of inspection by the MMM method of a shaft in a satisfactory condition

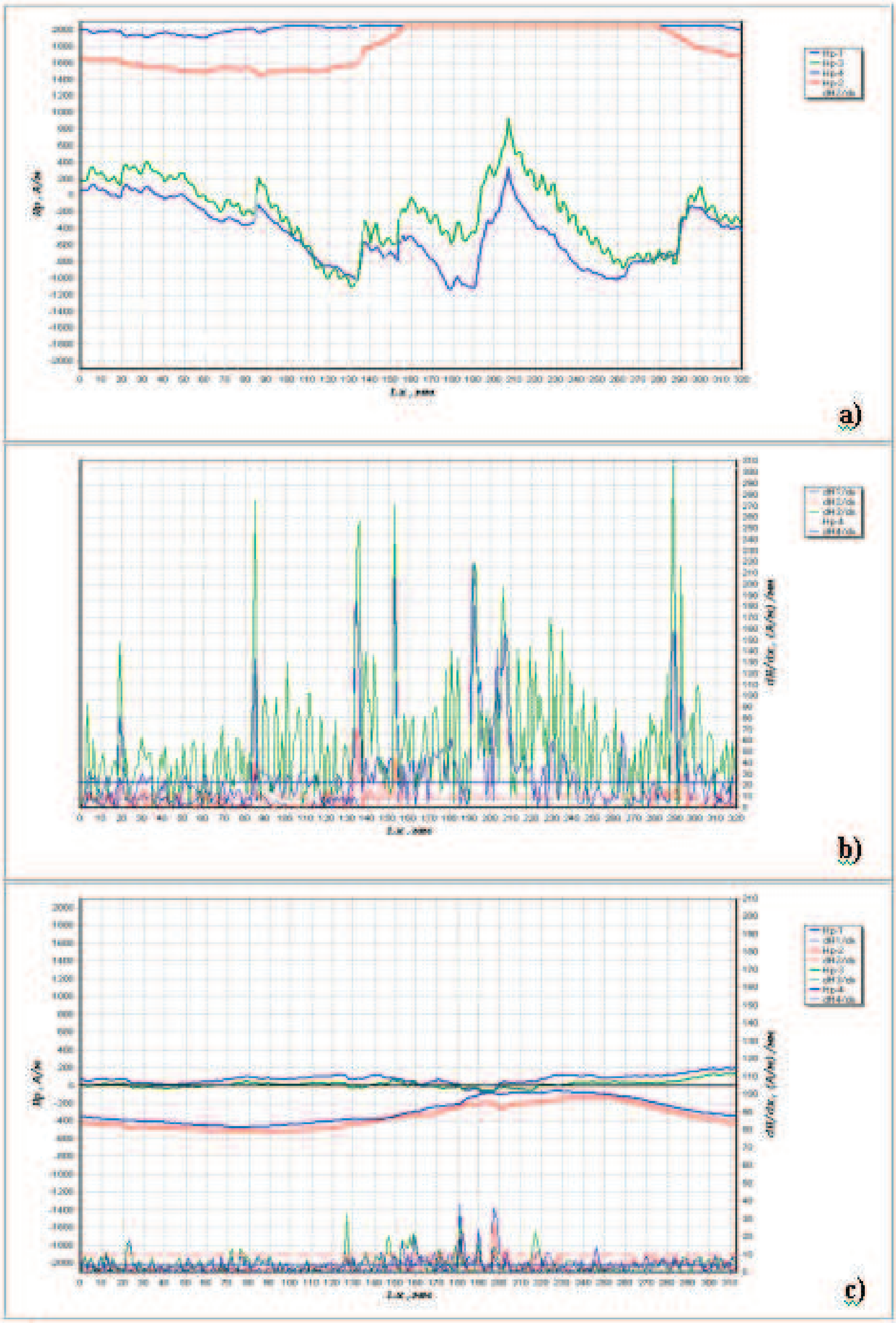


Shaft 1. Section 3.

Fig. 9*b* Results of inspection by the MMM method of a shaft with a developing crack.

Fig.*11a* and *11b* shows the results of a drive shaft inspection in section 3 with a repair deposition at Novosibirsk Electric Locomotive repair Plant.

Fig.*11c* shows for the sake of comparison the results of a similar shaft inspection in section 3 without deposition.



H_p field gradient distribution

Fig. 11. Results of inspection by the MMM method along the shaft perimeter with a repair deposit (a, b) and of a deposit-free shaft (c)

Fig.11 demonstrates an abruptly different shaft state in splines area. It is obvious that after splines deposition high residual stresses remain causing in operating conditions the accelerated shafts failure. It should be noted that till date there are no methods of residual stresses inspection suitable for wide practical application at machine-building and repair plants. In this connection it is recommended to use the MMM method for solution of this problem. Express inspection by the MMM method can be carried out after performing deposition on drive shafts, and shafts with high level of residual stresses should not be admitted for operation.

4.4. The technique for railway motor spline junctions inspection.

Photo 4 shows the picture of one of the splines. Fig.12 shows the scheme of gear wheel splines inspection using a four-channel scanning device. The direction of scanning at inspection of mating part splines is indicated with arrows in Fig.13. At inspection on measurement channel (sensor) is installed on the pin and another – into the slot. At a four-channel measurement scheme two pins and two slots may be simultaneously inspected. Thus, all slots and pins of the same spline are sequentially, and then all pins and slots of a drive motor mating spline are inspected in a similar way. Zones with maximum values of the field gradient *(dH_p/dx)* are recorded at inspection on each pin and of the field gradient $(\Delta H_p / \Delta b)$ between the two adjacent measurement channels (pin-slot), where Δb - is the base distance between the two measurement channels (sensors) set in the menu at the TSC-1M instrument at adjustment. These areas are marked with paint or a soft-tip pen on a specific pin surface of a specific spline junction.

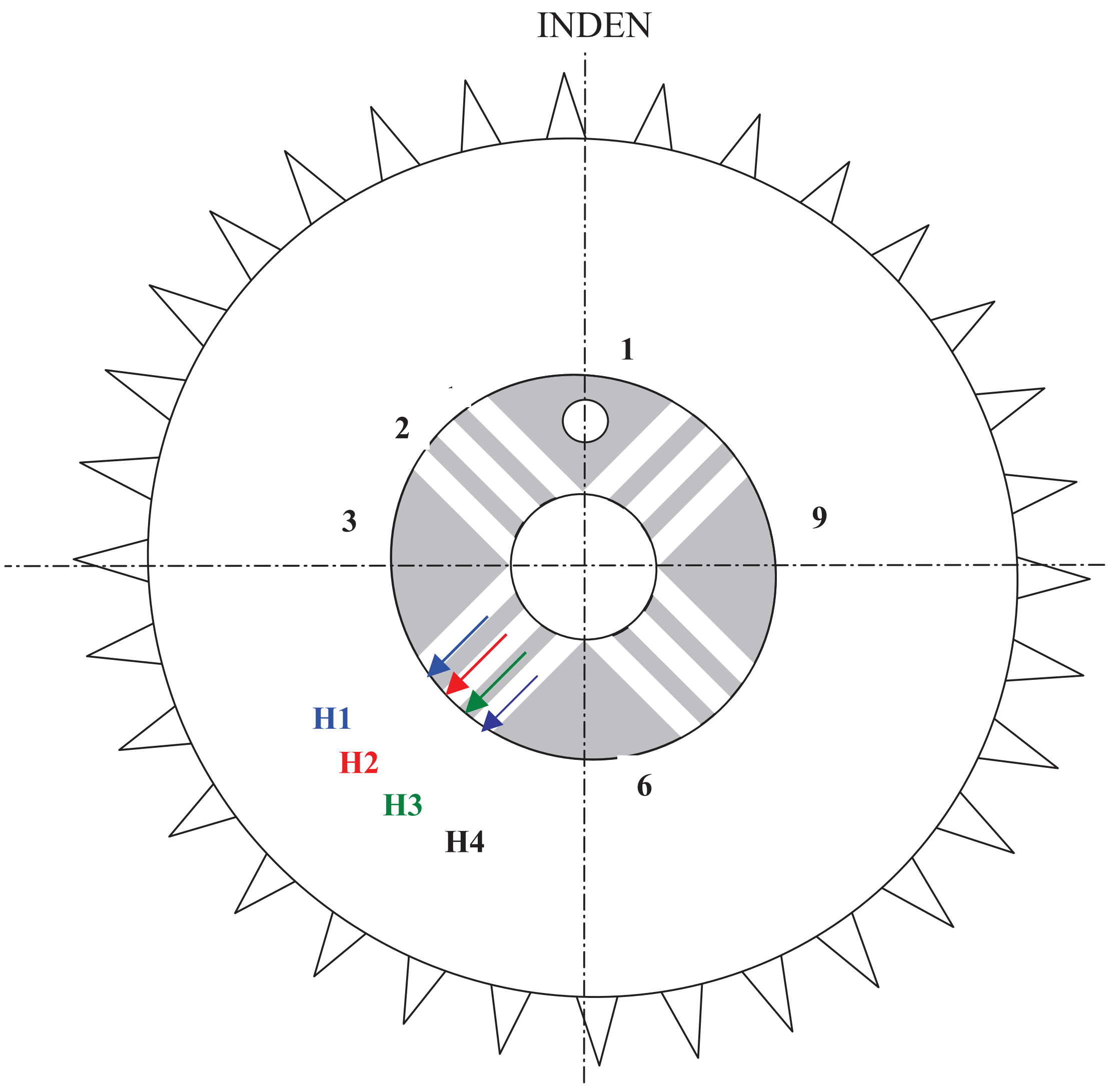


Fig. 12 Scheme of spline joints inspection on a wheel

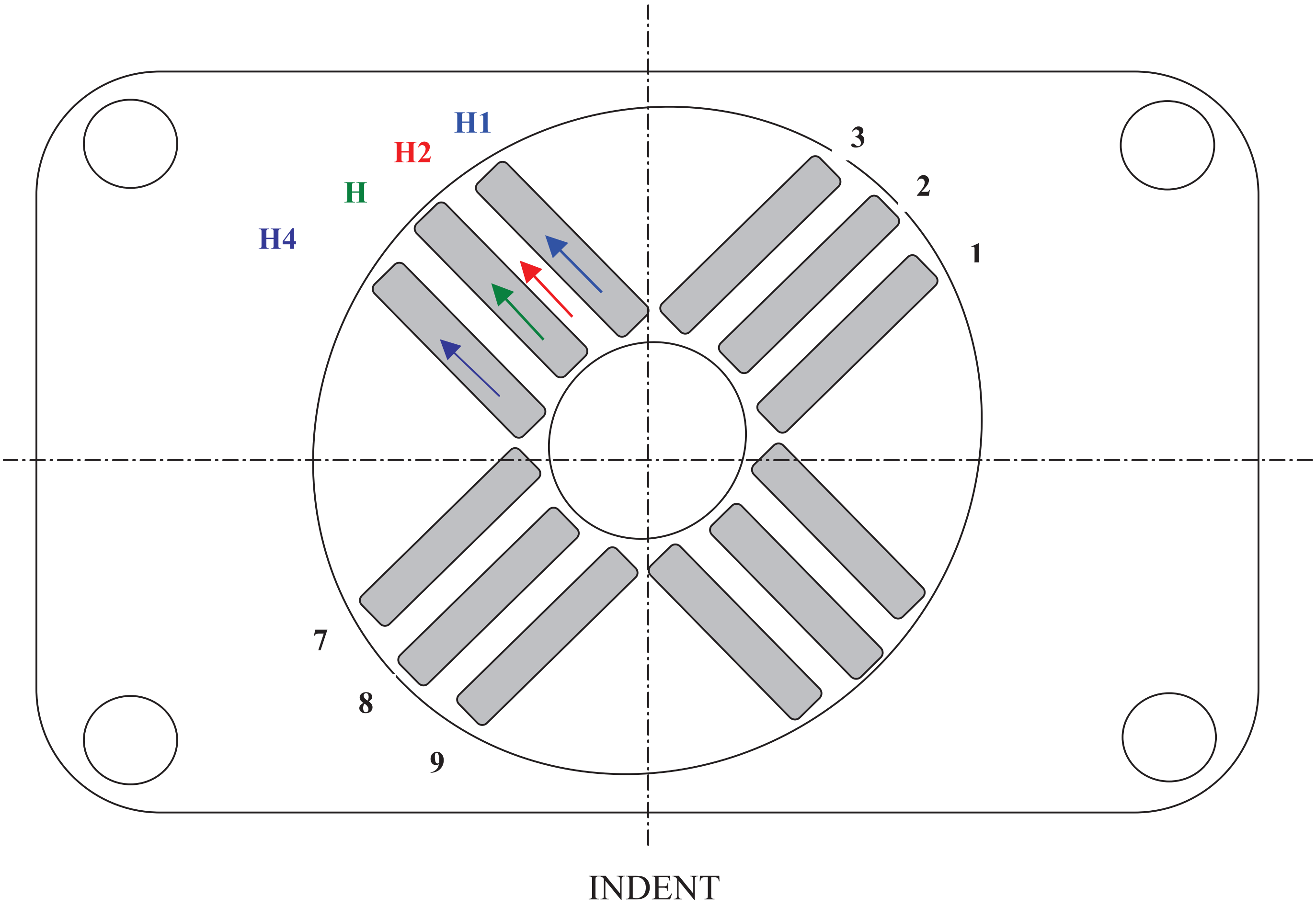


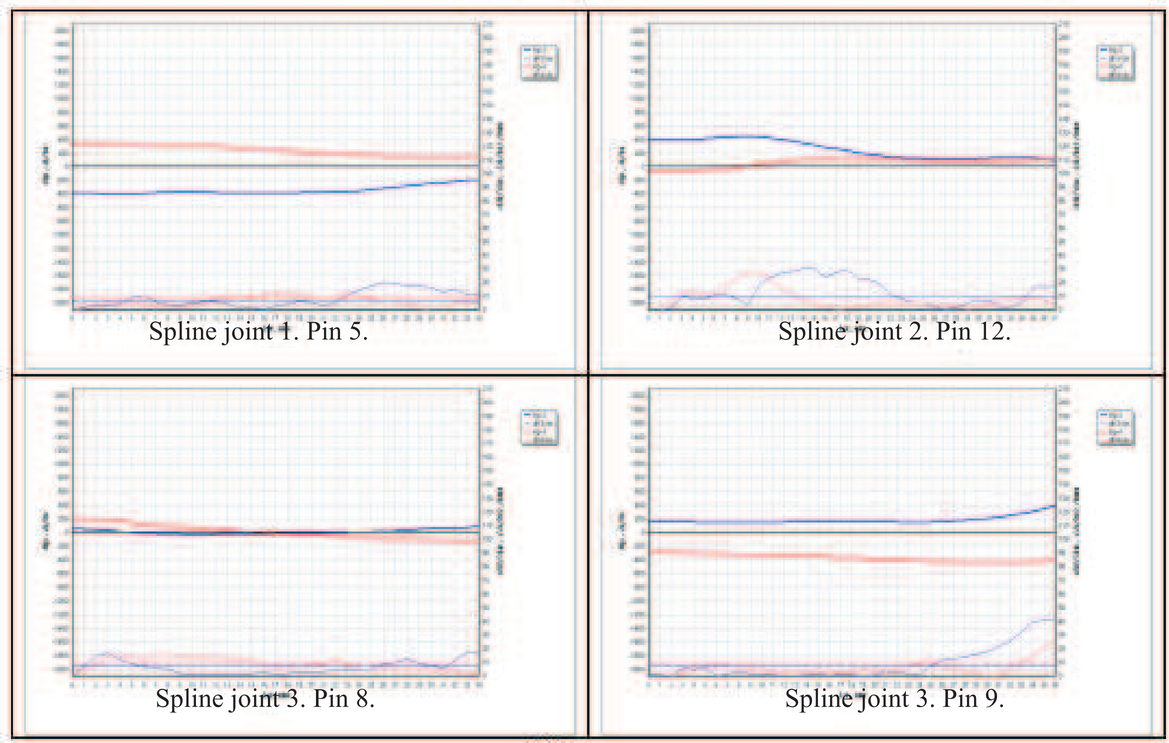
Fig. 13 Scheme of spline joints inspection on a counterpart

Spline junctions, on which field gradient values of $dH_p/dx \geq 300\text{-}400\times10^3$ (A/m^2) on individual pins or filed gradient (pin-slot) at a based distance Δb values of $(\Delta H_p/\Delta b) \geq 200\text{-}300\times10^3$ (A/m^2) were recorded at inspection, are marked with a special symbol, sorted separately and referred to the shaft group subject to repairs. On pins and slots of spline junctions in areas of maximum gradient values it is recommended to perform metal surface grinding and to repeat inspection. Grinding should be carried out before the time the magnetic anomalies disappear in SC zones. If after grinding of individual pins and slots geometrical shaft dimensions are within acceptable limits, such shafts may be admitted for further operation.

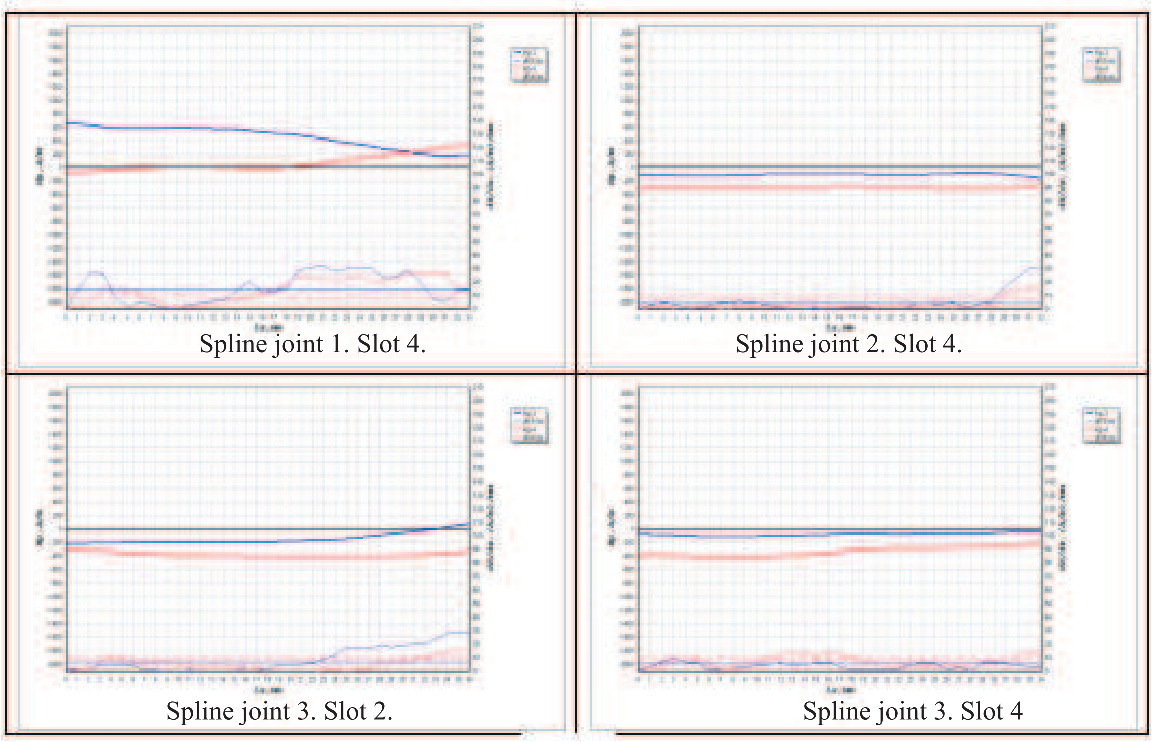
Spline junctions, on which at pins and slots inspection the recorded field gradient values by each measurement channel and at a base distance between the adjacent measurement channels (pin-slot) did not exceed the above indicated limiting values, are referred to the group of shafts with satisfactory state and may be admitted to further operation.

Note: On spline junctions with high artificial magnetization (the H_p magnetic field on pins shaft butt-ends is greater than 1000 *A/m*) the acceptable values of the field gradient $(dH_p/dx$ and $\Delta H_p/\Delta b)$, are, as a rule, large (3-5 times greater than the field gradients values at natural magnetization). The limiting values of field gradients for such spline junctions are established experimentally based on the inspection results statistics set.

Fig.14 shows inspection results of individual pins and slots of a spline junction in a satisfactory state. Fig.15 shows inspection results of individual pins and slots of a spline junction with field gradient values by individual pins exceeding the above-indicated limiting values.

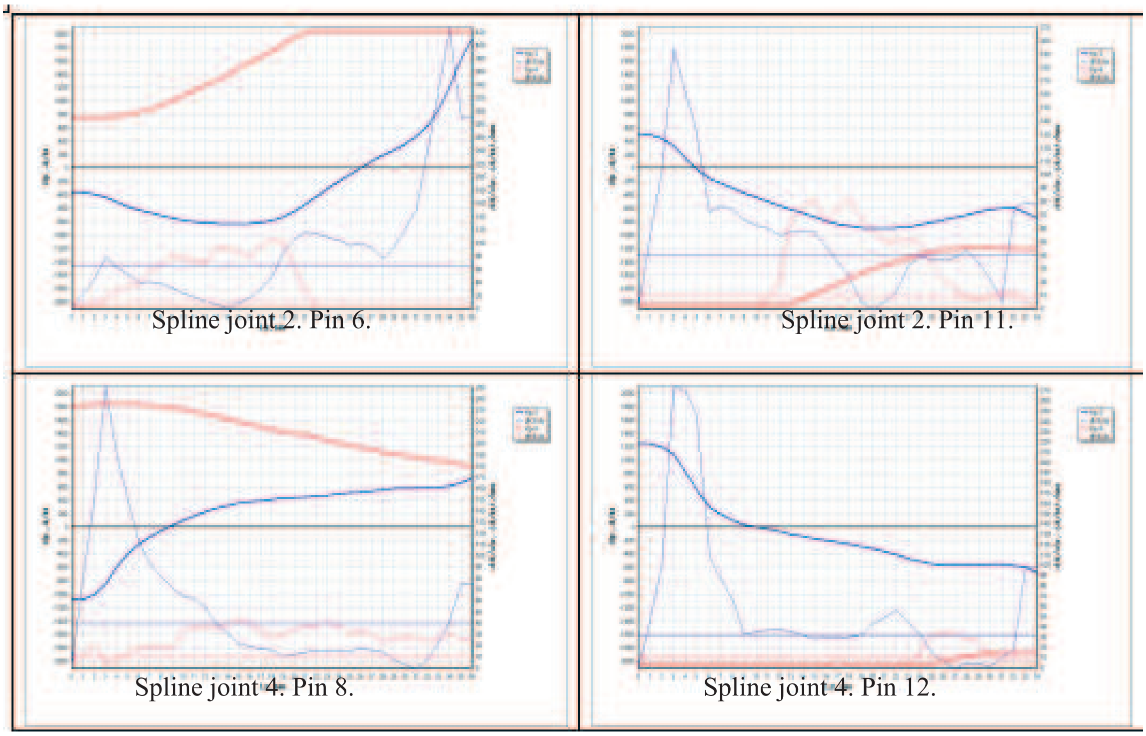


Pins.

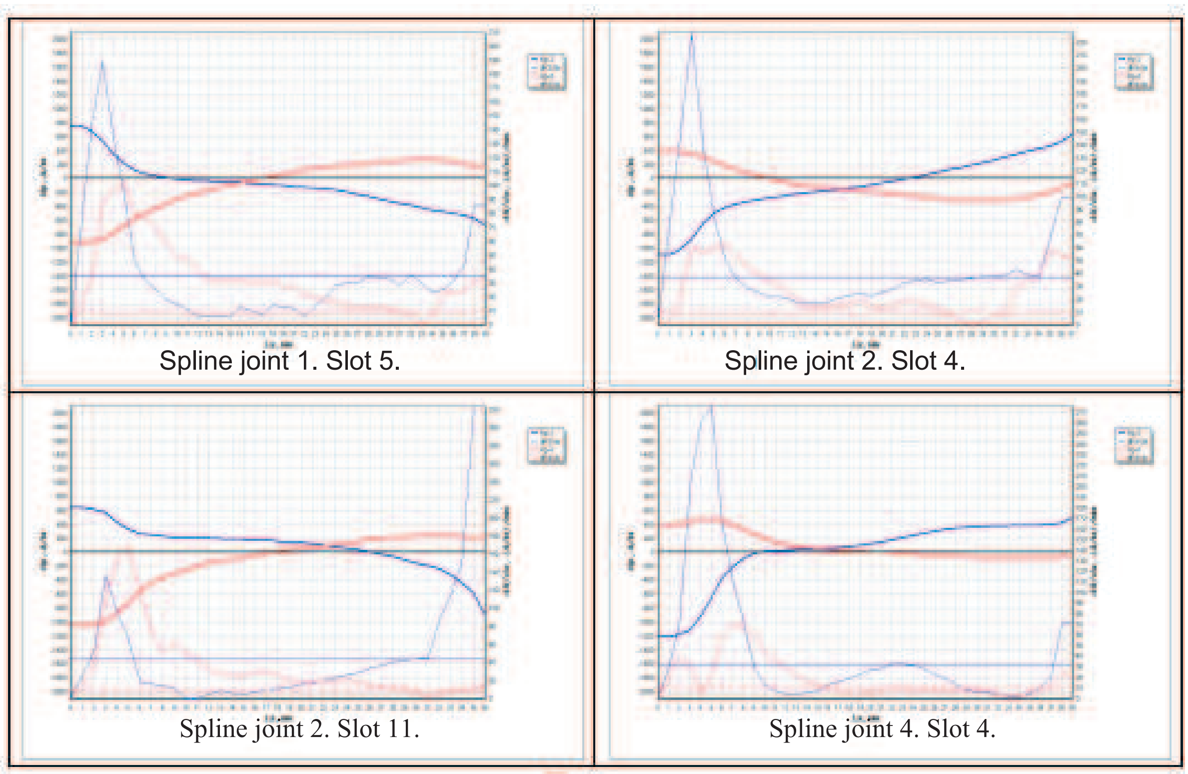


Slots.

Fig. 14. Inspection results of individual pins and slots of spline joints on a wheel being in a satisfactory state



Pins.



Slots.

Fig. 15. Inspection results of individual pins and slots of spline joints
with maximum values of the H_p field gradient

5. REGISTRATION OF INSPECTION RESULTS

5.1. Appendix 2 gives the form of the Report on MMM-inspection results. Results of inspection by other methods are written as separate reports. Results of all carried out measurements are written as a Conclusion supplemented by parts logbooks.

The Conclusion shall indicate:

- inspection scope;
- description of inspection results with indication of SCZs in the part logbook;
- conclusions and measures on parts reliability assurance.

5.2. Specialists and Heads of organization performing inspection are responsible for quality and authenticity of works on parts inspection. The Conclusion is signed by work executors and by the laboratory or Technical Control Division manager.

6. QUALIFICATION OF SPECIALISTS

6.1 Obtaining of reliable results at carrying out pipes magnetic inspection depends to a great extent on experts qualification and experience.

Persons trained specially in metal magnetic memory method with certification by Level I and II at "Energodiagnostika" Certification and Training Center (Moscow) are admitted to carry out inspection.

6.2 Persons having knowledge of "CS" electric locomotives Repair Rules" (CT/4015) are admitted to carry out inspection.

6.3 Qualified HPS engineering staff of the maintenance company conducts general supervision of works on electric locomotive parts diagnostics. Expert certified by Qualification Level II signs the conclusion on MMM-inspection results.

7. SAFETY

7.1 Persons involved in electric locomotive parts inspection should know and observe safety rules established for employees of this enterprise.

7.2 Prior to access to magnetic inspection, all persons involved in the work should pass an appropriate safety instruction with signing in a special log.

Characteristics of magnetic instruments designed and manufactured by "Energodiagnostika" Co. Ltd.

Table 1.

Instrument name	Type of indication	Magnetic field Hp intensity measurement range, A/m	Instrument designation	Power supply	Overall dimensions	Weight, kg
TSC-1M tester of stress нconcentration-system for measurement, recording and peocessing of equipment's stress-strained state using the method of metal magnetic memory	liquid-crystalline graphic indicator sound signal	±2000	Detection of maximum stress concentration zones	Off-line mode - storage batteries (4x1,2V) orgalvanic elements (4x1,5V) steady-state mode 5-6 V	230x105x40	0,5
TSCM-2FM tester of stress concentration magnetometric	LED digital indicator, sound signal	±1999	Detection of maximum stress concentration zone	Galvanic elements (2x1,5V) or storage batteries (2.x1,2V)	120x60x25	0,3
EMIC-1 (2) electromagnetic indicator of cracks (flaw detector)	LED indicator, sound signal	------	Bdetecting of surface cracks 0,2 mm deep and greater	storage batteries (2.x1,2V),	160x85x30	0,35