Analysis and Review of NDT Instruments Used for Rails Inspection at Russian Railway Roads

Vitaly I. GORDELY, VIGOR, Moscow, Russia

A rail is a most important element of a railroad tract. It experiences multiple loads reaching 50 MPa and over caused by the rolling stock passing on it. At that, movement is accompanied with short hits whose force grows as its speed increases. Besides, there are thermal loads of seasonal nature of up to ±40^0C, as well as additional daily thermal shocks reaching ±20^0C. At that, rail experiences chemical, corrosion, electromagnetic static loads rendering its operation conditions significantly harder. It is exposed to moisture and oils, acids and alkali that are always present in the air. Frequently there are stresses occurring under the action of deformation of crushed stone pad, crossties, and soil itself, residual thermal stresses, strength heterogeneity and so on. Local and extended rail surface irregularities occur, there are uneven joints, there is presence of ice, snow, and water facilitating occurrence of additional loadings.

Such complex impact results in rails' accumulation of fatigue and thermal damages, giving birth to intercrystalline corrosion. Both surface and internally located defects appear, which redistribute mechanic stresses inside rails and break their heterogeneity. This frequently leads to their destruction resulting in huge material and human losses. For instance, about 30% of all accidents that happen in railroads of the country occur specifically because of rails breaks.

This happens not only in Russia. For example, in France, nondestructive check reveal annually up to 5 thousand rails to be replaced because of fatigue fractures and other inadmissible defects. In the Netherlands, they discover on average 0.07 defects per a kilometer of a railroad track. In Italy, after examination of 3500km of railroads in 1990, they revealed 1156 transversal fractures, 65 horizontal, 21 radial fractures from bolt holes, 732 longitudinally vertical fractures, and 22 fractures in welded joints. At that, there was one acutely defective rail per every 20km of track. Nevertheless, during the same year in Italy there were 300 breaks of rails [1]. Only for the years 1988 – 1988, in USA railroads, the number of crashes due to defective rails amounted to 25% of their total number, 40% of losses from accidents occurring particularly for this reason [2]. In this connection, diagnosis of rail performance is a topical task. The problem becomes much more acute in case of rail wear-out, their life span being exhausted, which is not a rare case in Russia.

An efficient, and in a number of cases, the sole possible method preventing occurrence of emergencies in railroad transport due to rail breaks because of defects arising in them, is nondestructive check methods and hardware. Indeed, in the beginning of the 1950s, the number of rail damages in the USSR per 100km of track reached 230 – 280 units per year, and this caused huge damage to the whole national economy. Therefore, measures were taken towards development and implementation of apparatuses and methods capable of doing nondestructive diagnosis of rails.

As a result, by now, the Nondestructive Check Service, the Ministry of Railways, is one of the most important, and special attention is paid to it's functioning. This Service has a distributed network of technical services, research laboratories, educational divisions, certification services and so on. In particular, timely distribution of nondestructive check personnel among the main transport branches is shown on Fig. 1.

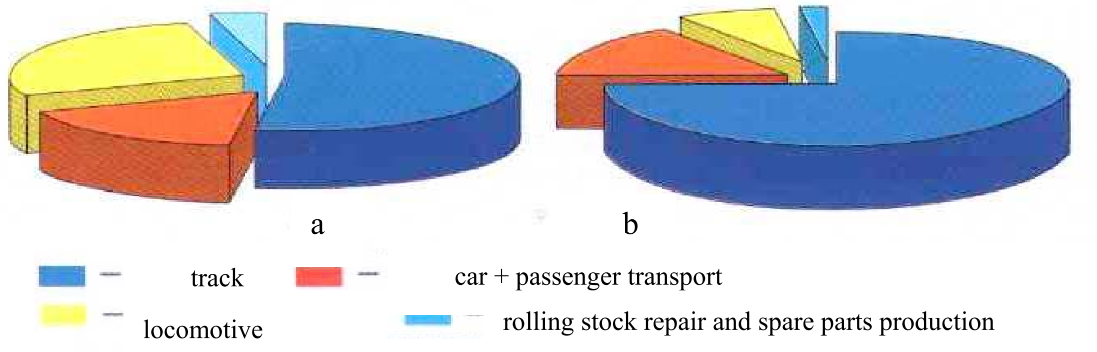

Fig. 1. Distribution of the number of nondestructive check divisions (a), and the number of specialists (b) among the branches of federal railroad transport

The Order of the Russian Ministry of Railways dated 16.08.94 No. 12C, for the purposes of saving resources and improving organization, consummated the "Provisions on the System of Maintaining Track Facilities in Railways of the Russian Federation" based on classification of roads by their operational characteristics. Besides, on the basis of order No. 12Ц, in 1997, the Russian Ministry of Railways approved and put into effect since 01.04.97 the "Provisions of the System of Nondestructive Check of Rails and Operation of Rail Defectoscopy Equipment in Track Facilities of the Russian Federation", which systematized the core changes in the system of nondestructive check of rails. They provide for development, manufacture, and supply to railroads of a set of new nondestructive check hardware. The necessity is noted of carrying out respective research development, designing, manufacture, and operational development of new mobile equipment determined by these "Provisions". This circumstance was taken into account in the R&D plans and financing of the RF Ministry of Railways. Thanks to this, the expenses only on acquisition of automobile railway cars and defectoscope cars during the years 2001 – 2005 are planned at 772.8 million rubles (in prices of 2000), and 316.6 million rubles is planned to be spent on continuous and secondary check defectoscopes.

In 1950 – 1990 nondestructive check of rails was mostly based on application only of ultrasound and magnetic mobile defectoscopes («removable bogies»), which were moved by one or two operators manually. By now, though, this arsenal has significantly expanded. This required introduction of a special systematization.

In accordance with recommendations of Chief Designer of Ministry of Railways for Nondestructive Check Professor A.K. Gurvich, its enlarged current structure in terms of applied equipment is given on Fig. 2.

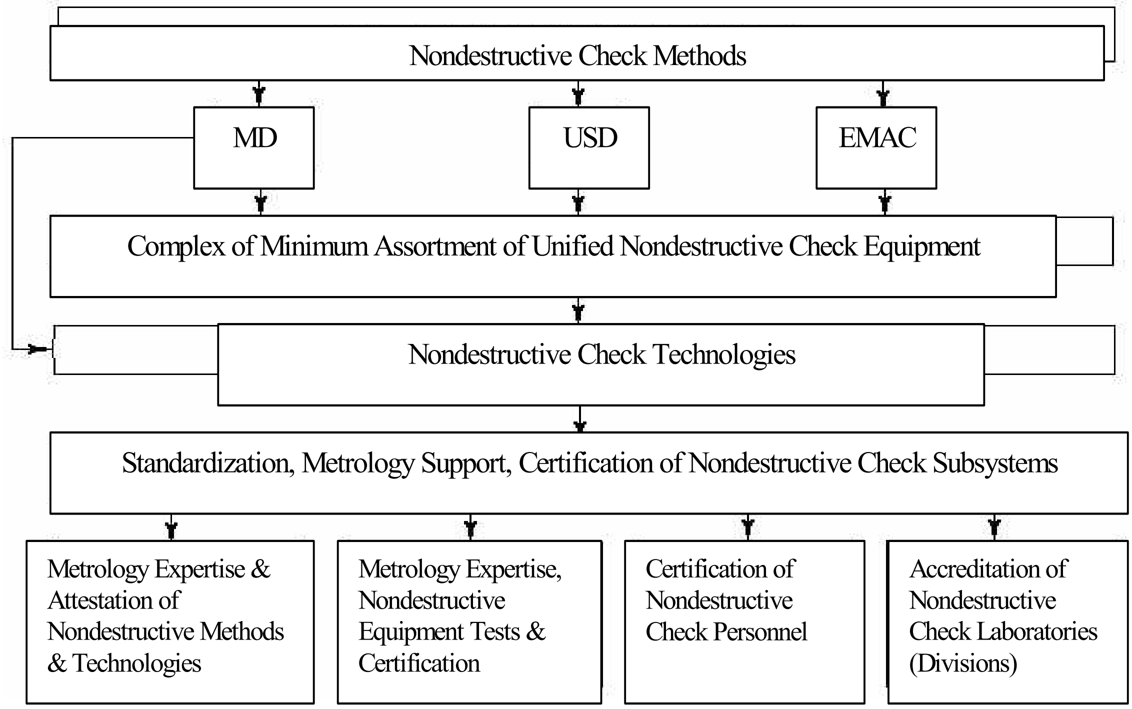

Fig. 2. System of mobile nondestructive check of rails

In accordance with this diagram, main methods for nondestructive rail tests are now magnetic (MD), ultrasound (USD), and electromagnetic-acoustic (EMAC). Distribution of the said nondestructive checks equipment by railroad transport items is detailed below.

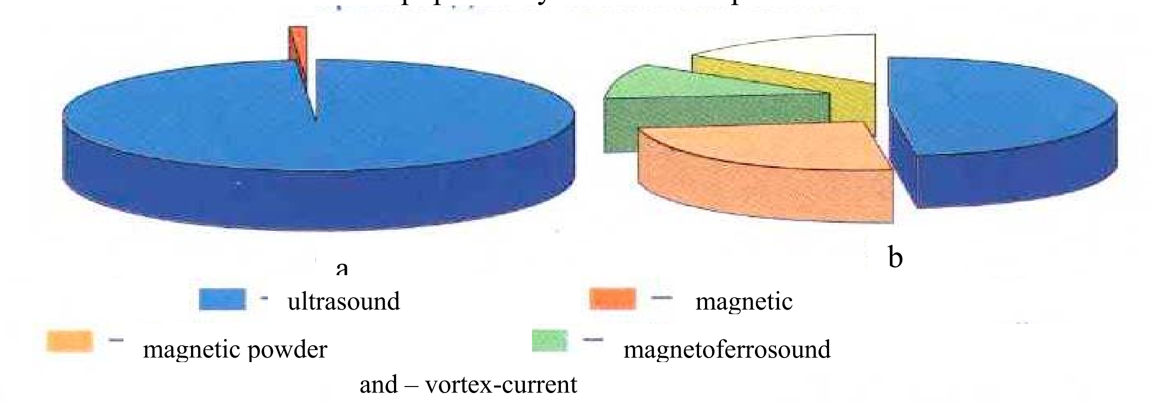

Fig. 3. Distribution of defectoscope equipment by the methods of checking rails (a) and rolling stock parts (b)

So, the main role in nondestructive check of rails is given to ultrasound methods, in case of inspection of rolling stock parts, other nondestructive check methods occupy a noticeable place as well.

Still, reliability of revealing defects in railroad transport is not limited only to hardware. For reliable performance of the whole nondestructive check service, the services of Metrological Expertise, Tests, and Certification of Nondestructive Check Equipment, Training and Attestation of Specialists are used. Laboratories and teams are being accredited; structures are singled out, which can be entrusted with performing so vitally important nondestructive tests. The activity of the said services is dedicated specifically to tackling these issues.

On the whole, in the railroad transport of Russia, 15 to 20 thousand employees of different qualifications (from an engineer to a laborer, see Fig. 1) are engaged in nondestructive check. About 10 thousand of various types of defectoscopes are in operation. They control annually only in the track facilities over 7 million km of track, 2.5 million of welded joints. By now these efforts have started to bring evident benefit. For instance, according to the data of the Russian Ministry of Railways, as a result of work of all nondestructive check structures in railroads of the country, 100 to 150 thousand units of defective rails are recalled annually, including 20 to 42 thousand of acutely defective, i.e. subject to immediate replacement. More than 70 thousand potentially possible breaks of essential facilities of track and rolling stock are prevented. This results in continuous improvement of the condition of rail stock of the country, and for the last 10 years, the number of acutely defective rails in the railroads of the country, revealed by defectoscope equipment, decreased almost 2-fold, the number of rail breaks reduced 2.7 times, and the number of accidents that occurred due to poor quality check decreased almost 5 times.

Nevertheless, the problem of safe operation of railroad transport cannot be yet considered fully resolved. Inspection reliability is up till now determined not only by equipment but largely by the qualifications, experience, conscientiousness of defectoscope specialists. Hence, the relative number of defects that led to rail breaks and not revealed at the fault of operators is still rather high (see Fig. 4):

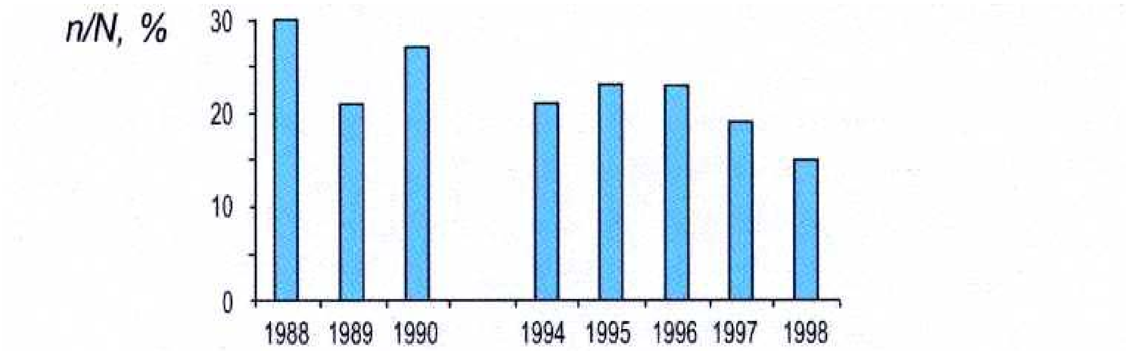

Fig. 4. Ratio of the number (n) of rail breaks because of defects that were not revealed by operators to the total number (N) of breaks per year

And though this ratio steadily goes down (from 30% to 17%), the share of this factor is still rather high. This depends on only on the equipment and operators but also on the level of organization of nondestructive check services. This circumstance is demonstrated by the following nomographic chart:

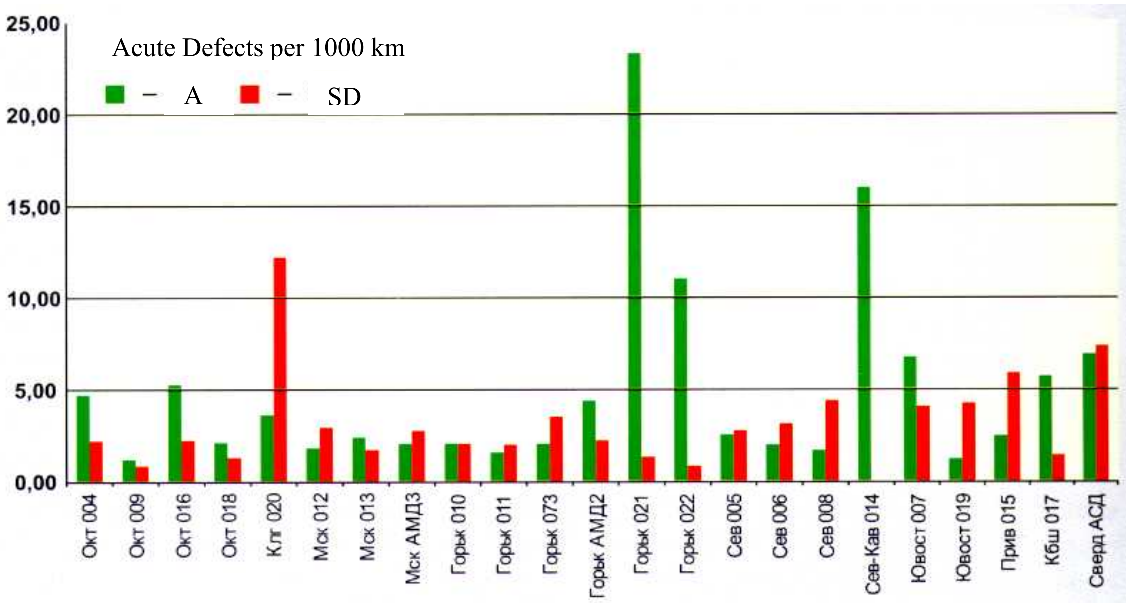

Fig. 5. Detectability of defects in rails with removable defectoscopes and defectoscope road cars in different railroads on the Ministry of Railways network

This also shows the nondestructive check equipment that revealed defects.

So great scattering for different railroads of the country using the same nondestructive check equipment evidences existence of sufficiently powerful not yet used resources.

In this connection, the acute necessity becomes evident of developing and introducing mobile systems of automated nondestructive rail check based on up-to-date scientific achievements of detection, registration, analysis, saving and transmission of data, which would be uniform for the whole country and allow application of same data processing methods. This way achieves not only unified and unbiased control but allows reducing its costs, eliminating the effect of subjective factors in it, including staff-related, ensures faster and more reliable results obtained.

Nevertheless, it is yet a comparatively long way to have this problem fully resolved, and in the railroads of the country rather large number of non-automated check means are still used. For instance, in 2003, out of the total number of 5449 nondestructive check units, only 117, or 2% were mobile. In general, pursuant to the specificity of operation and quantity, these equipments are divided into the following classes:

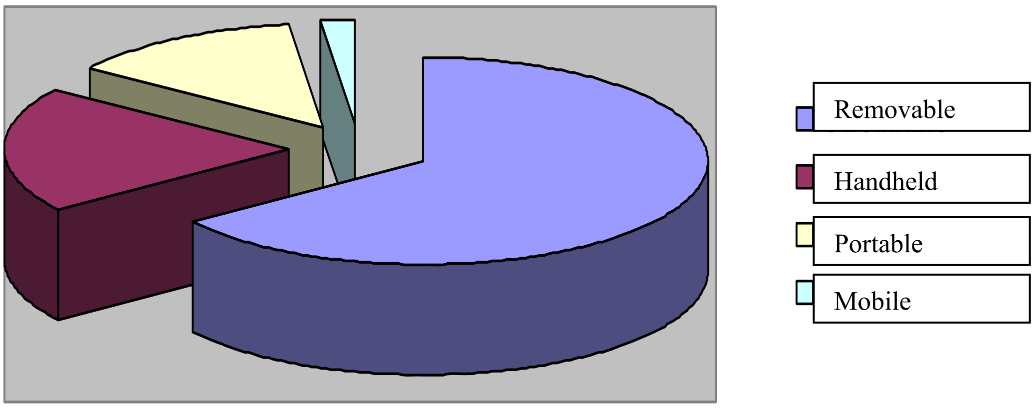

Fig. 6. Distribution of nondestructive check equipment of railroad transport by classes

That is, 3530 units or 65% belonged to removable defectoscopes, 1060 units i.e. 19.5% - to handheld, and 742 e.i.13.5% - to portable. At that, portable defectoscopes include defectoscopes of the 2nd generation (POISK-2 and 10E), microprocessor-based defectoscopes of the 3rd generation (Avicon-01, RDM-2), also all microprocessor-based units of the 4th generation with continuous registration of the inspection results (ADS-02R, RDM-2R, Avicon-01R, and RD-12KR).

Handheld defectoscopes are used to check rails in difficult of access places and parts of rails. They are divided into those checking with continuous scanning (RDM-1, DIO-562R), and those with step-by-step scanning (POISK-4 and POISK-14). Portable ultrasound defectoscopes are applied for manual check of welded joint, bolt joints and some cross-sections of rails. Microprocessor-based defectoscopes are differentiated into those without registration of inspection results (RDM-3), those with registration of results (PELENG-UD2-102, AVICON-02R), and those registering concurrently both the results and the main parameters of inspection (UD4-G).

The mobile check means are those that require coupling with the locomotive (defectoscope cars), self-propelled (defectoscope road cars), combined self-propelled (defectoscope traction engines).

Obviously, only mobile defectoscope means allow creating conditions for most complete processing and storage, and transmission of information. They move at relatively high speeds, provide for incomparable to other means comfort conditions for equipment and attendant personnel. Hence, future belongs to them. At the same time, sensitivity of inspection using contemporary mobile means is yet lower than in other means of checking.

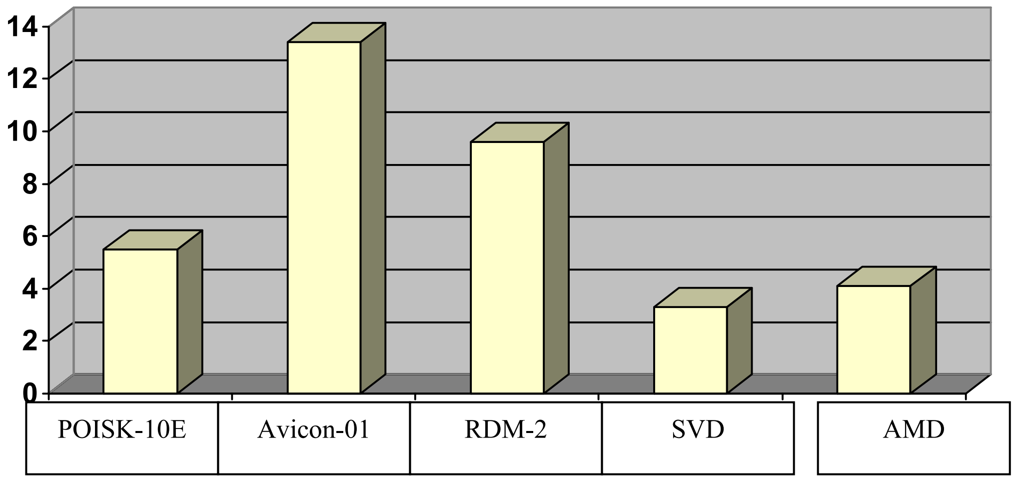

Fig. 7. Actual (year 2003) technical efficiency of continuous nondestructive check means of rails en route (the number of detected defects per 1000 km).

At the same time, things don't stand still and sensitivity of detecting defects with the help of automated check systems (AD) significantly grows with years. Respective results are demonstrated in the figure below:

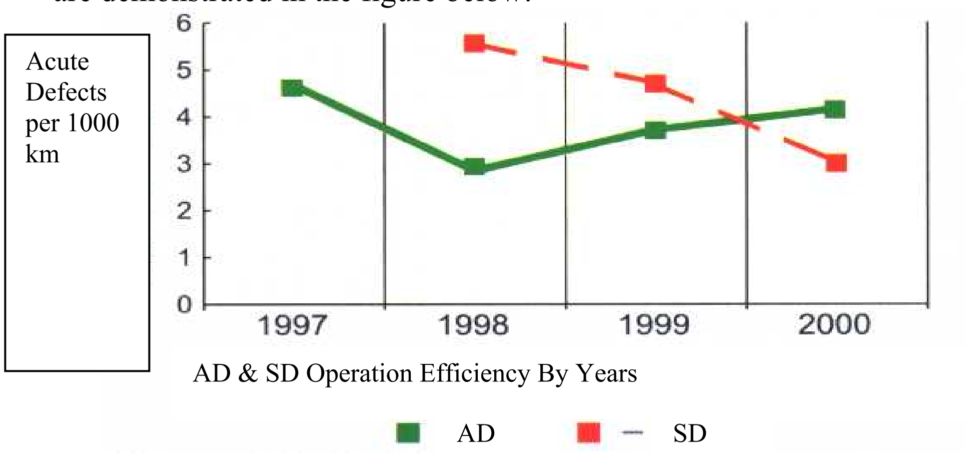

Fig. 8. Changes in the results of work of road car operators by years

This is to some degree explained by the author's work in the field of creating mobile automated means for nondestructive check of rails. It has been carried out since 1991; as a result NPP «VIGOR» now, together with contractors, develop and supply a considerable number of road cars and defectoscope cars for nondestructive check of rails. In total, as of today, NPP «VIGOR» supplied the RF Ministry of Railways with about 50 road cars and more than 10 defectoscope cars.

Nevertheless, the reasons for lower sensitivity of road cars compared to removable defectoscopes are quite objective. In fact, now combined magnetic and ultrasound checking equipment is usually used in them, the magnetic channel detecting only defects located in immediate vicinity to the surface the head is rolling on (3 – 5 mm).

Ultrasound check features wider possibilities but it the course of its application the following specific difficulties arise. This method does not guarantee detection of defects of the second group if they have a mirror reflection surface or located other than in the working plane of rail head (when the main scheme of sounding is applied, i.e. both converters are turned at an angle of 55° towards the working rail head plane). The efficiency of ultrasound method noticeably falls down in case of operation in low-temperature conditions.

Besides, in different parts of the track the roll surface is severely soiled with lubricant leaking from the axle-boxes of rolling stock, first of all, freight one that is equipped with roller bearings. During intensive downhill breaking axle-boxes are heated, causing more frequent leakage of lubricant onto the rail. During operation rail surfaces get cold-hardening, its depth reaching 8mm. Also increased and uneven wear of rails, metal floating and surface «peeling» take place. All this not only disrupts the acoustic contact of sensors with the rail surface but also increases the structural noise level, sound reverberation, particularly in case of acceleration.

Therefore, an essential field of joint work now is development and introduction of electromagnetic - acoustic converters (EMAC). Their specific features are:

– excitation and registration of ultrasound oscillation without using contact fluid;

– the possibility of generating and registering ultrasound oscillation of different polarity (longitudinal, transverse), of surface waves, as well as signals with rotating polarization signal;

– the possibility of exciting and registering ultrasound oscillation in a wide range of variation of frequencies, temperatures and speeds of inspected objects' movement;

– existence of an air clearance significantly raising the reliability and life span of ultrasound converters, mechanic equipment and, as a consequence, of the whole set of checking equipment in general.

Besides, requirements to the quality of surface preparation of inspected objects are much lower in case of EMA-method implementation compared to contact methods. This opens up the possibility of implementing nondestructive check methods in the fields and in respect of objects, where such methods have not been practiced up till now.

Relatively low compared to contact methods sensitivity of EMA-check is made up by application in the plants of powerful semiconductor valves, low-noise pre-amplifiers, permanent magnets with high magnetic induction, application of special information processing methods.

The author, together with NPP "VIGOR" specialists, performed an analysis of modern achievements in the field of EMA-conversion, studied the design solutions in creating EMAC for checking rails that are used by other companies. Main requirements to sounding schemes and EMAC have been worded; a set of necessary investigations has been carried out.

With regard to the results of many years of investigations and latest works done at NPP "VIGOR", methods and designs of EMA-Converters for excitation and receipt of ultrasound waves of different types during inspection of rails in rail-welding trains have been developed.

NPP "VIGOR" pays much attention also to development and introduction of up-to-date analogue and digital systems of generation, receipt of signals of different classes, information processing. In particular, to this end, «single-storey» electronic rack Poisk – 20M1 with LCD display has been developed and is used in ultrasound channel of road cars and defectoscope cars.

LCD unit is an updated version of CRT equipment of defectoscope «POISK-20» complemented with synchronizer and defects signaling device (SSD). The functions performed by the unit are the same as the functions of separate CRT and SSD units, processor and control panel board, which are mounted on the racks. Connection with other units of electronic rack «POISK-20M1» is made with flexible loops using modern computer plug-and-sockets.

Control units allow both operational (switching of channels, regulation of sweep duration and delay, increasing or decreasing the amplitude of signal reflected on the screen, vertical signal offset), and preliminary adjustment of rack «POISK-20M1» (changing the SSD unit parameters).

Besides, new capabilities of rack operation have been introduced:

- simultaneous observation of all 10 working detection channels;
- observation of signal with filling from below;
- current time display and its correction.

NPP "VIGOR" continuously works on improvement and increasing reliability of performance not only of the defectoscope complex on the whole but its separate units as well. For example, the design of remote marking panels, the design of the follow-up system elements was elaborated. At present, the electronic unit of ultrasound channel recorder is made as one board, which significantly improved reliability of recorder's performance.

At present NPP "VIGOR" has completed and is carrying out operation testing of «Automated Software & Hardware Complex for Registration, Storage, and Processing of Signal from Finders of Defectoscope Car, Defectoscope Road Car» - «Poisk-2000». It surpasses, in terms of its parameters and capabilities, all existent system of similar purpose (such as «Poisk-20 – SAROS - VIP», «AVICON-03»", «ECHO-R-CRUZ» and others).

In connection with wide application of mathematical methods of control and processing of information, the combined types of road cars and defectoscope cars use software versions allowing comparison of a doubtful area versus the results of previous trip (SAROS – version 3.3; VIP – version 6.4). These versions permit assessing changes in defect sizes over the time period elapsed since the last previous trip, hence, increasing reliability and efficiency of inspection results.