

Ultrasonic testing of discontinuities of metal of gear blanks of rolling stock

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S u m m a r y . Was made an analysis of the location of metal's discontinuities of gear wheels blanks of locomotive of rolling stock. There is shown that gear wheels blanks of rolling stock might have unacceptable internal discontinuities of metal of flat shape, and planes of these flat discontinuities might be situated in both the radial and axial directions of the blank. The necessity of conducting of ultrasonic control of gear wheels in radial and axial directions is substantiated. Was proved that conducting of ultrasonic control leads to prevention of getting into exploitation of gear wheels with unacceptable discontinuities and also excludes technological operations on defective blanks, and as a result saves money.

Key words: gear blank, discontinuities of metal, magnetic particle method, ultrasonic control in radial and axial directions.

INTRODUCTION

In the transport system of Ukraine railway transport has the leading role [1]. Globalization of economics leads to the development of international partnership and as a result to increasing flow people and goods [2].

Strengthening of interconnections of national economics needs high quality of transport provision. The global transport system consists of integrated national transportation systems, which ensure the implementation of both internal and international transportation [3].

The transition of Ukrainian economy to a market economy in and its integration into the global economy contribute to the expansion of economic relations of enterprises in Ukraine with foreign enterprises [4]. In the Transport Strategy of Ukraine till 2020 (the Decree of the Cabinet of Ministers of Ukraine dated 20.10.2010, the, № 2174) noted that transport is one of the basic branches of the national economy. The realization of this strategy aimed at ensuring the effective functioning of the transport system, will accelerate the pace of integration of the national transport system in the European and global transport system [5].

The integration of the transport system of Ukraine into European and world system requires compliance with international norms and standards in various fields, including technical one. Competition in the global transport market requires high technical and technological level, of transportation safety [6, 7].

Because of the wear and tear of railway rolling stock, which is one of the main part of the production assets of the railway, about 80%, is needed to upgrade railway rolling stock of Ukraine [8, 9].

Condition of railway rolling stock and its low technological level does not respond to modern requirements of the railway transport.

The economic efficiency of railway transport is largely dependent on operability of rolling stock.

Modern trends of development of railway transport of Ukraine are inseparably linked with the growth of the significance of the results of non-destructive control for improving the quality of parts and units of rolling stock. Questions of quality control in the manufacture of modern rolling stock become especially important in provision the security exploitation of rolling stock. Timely detection of defects in the production of metal allows both reduce the cost of technical operations in case of a defect in the blank and prevent getting into exploitation of parts and components with unacceptable defects of metal, which are the effective measures of preventing accidents.

The increase in traffic density and speed of rail is accompanied by increasing cyclic, temperature and stress impacts on parts and components of the rolling stock [10].

Discontinuities of the metal are stress concentrators and operation may be the first step to a premature fatigue failure of parts and components of the rolling stock [11].

To avoid getting into exploitation of important parts with unacceptable discontinuities of metal is needed non-destructive control of important components of railway transport, as in the manufacturing process as well as in the current repair. That is why, works related to the analysis of metal discontinuities of critical components and their identification by nondestructive methods are relevant.

In works [12, 13] was analyzed the location of discontinuities of metal bandages of wheel pairs, which occur during the manufacture of this bandages. Given the characteristics of the location of discontinuities of metal near the landing surface in the bandage [14] is presented an improved definition of ultrasonic control. In work [15] are given the results of the analysis of detected surface defects of metal of wheel pairs. The necessity of further improving the visual control is proven. In work [16] is given the analysis of the location of discontinuities

of metal of casting bogie frames that occur during the manufacture of castings and features that make it necessary to define additional developments of identifying such discontinuities under ultrasonic control. Questions of improvement of the reliability of the results of ultrasonic control of locomotive rolled wheel centers during the manufacturing process are considered in work [17].

In work [18] the question of the appearance of fatigue cracks on the rail-axes. Was proved the necessity of improvement of ultrasonic control for the diagnosis of axes. In work [19] observed decrease in the spectrum frequency of the reflected echo signals from the bottom surface under the discontinuities with an increase in the size of the lack.

Destruction of elements of gears of the rolling stock in exploitation is considered in works [20-25].

The identification of the location of metal discontinuities that occur during the manufacture of gear wheels gear traction locomotives is poorly investigated.

The aim of this work is to determine the location of the discontinuities of metal of gears of locomotive's traction transmission.

MATERIALS AND METHODS

The objects of investigations were gears made of steel 20C2N4MA and gears made of steel 45CN. Gears made of steel 20C2N4MA were hardening with the help of chemical heat treatment of the surface (cementation). Gear wheels made of steel were hardening by high frequency currents. Table 1 shows the comparative analysis of the chemical composition of the investigated steels [26].

Table 1. Chemical composition of steels for the manufacture of gears

Steel	C	Mn	Cr	Ni	Mo	S	Si	P
20C2N4MA	0,16-0,22	0,30-0,60	1,25-1,65	3,25-3,65	0,2	0,035	0,17-0,37	0,035
45CN	0,41-0,49	0,50-0,80	0,45-0,75	1,00-1,40	0,30	0,05	0,17-0,37	0,04

According to [27], gear blanks and gear wheels are made by forging, hot punching,

rolling with forging or hot punching with rolling. Technical conditions set the normative requirements to unacceptable discontinuities of metal on the working surfaces of the wheels and gears.

The visible surface defects were detected visually. Cracks were detected by magnetic particle technique in accordance with State Standart 21105 [17]. For exploration of discontinuities in the metal of gears and cogwheels was used magnetic particle method of control that allows to reveal cracks with opening from 0,002 mm. The type and method of magnetization was chosen depending on the nature and orientation of the defects to be detected. The best condition for the detection of defects - the perpendicular direction of the magnetizing field to the plane of the alleged defects. If required the detection of defects of different orientation magnetization was used in two or three mutually perpendicular directions.

Additional researches of discontinuities were made by ultrasonic echo impulse method of control with the help of flaw detector UD2-70 at the frequency of 2.5 MHz with a maximum sensitivity of 7.1 mm².

To set up sensitivity appropriate to apply the artificial defect type of flat-bottomed hole, which satisfactorily simulates flat discontinuities identified in gears.

From steel round bars were manufactured samples of cylindrical shape with a diameter of 60 mm and a height of 60 mm (Fig. 1, b). In one flat surface at the center are performed holes with a flat bottom made by drilling, diameter of holes is 3 mm and they are located at the minimum, average and maximum depth. After applying a contact liquid (industrial oil) the ultrasonic transducer was placed on a flat surface of the sample, opposite to the plane with drilling (Figure 1). Before testing the investigated sample surface was grind to $R_a = 6,3$ micrometers.



Fig. 1. The steel sample with an artificial reflector - drilling with a flat bottom: a - general view of the sample, b - a flat surface scanning with an ultrasound transducer, c - the flat surface of the sample with a flat bottom made by the drilling

RESULTS AND DISCUSSION

The analysis of the defects that were identified during the production of locomotive gears revealed both surface and internal discontinuities in metal. Was found that internal discontinuities in metal occur during the manufacturing process. It was also found that certain discontinuities located on the inner surface. Fig. 2 shows a crack occurs during the process of hardening and grinding rims.

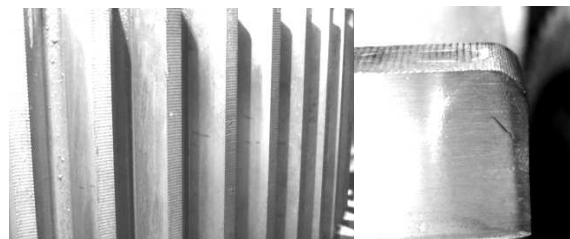


Fig. 2. Cracks on the working surface of the cog occurs during manufacturing gear

On Fig. 3 shown a side surface of the locomotive gear with an internal defect that goes to the working surfaces of the adjoining

cogs (Fig. 3a) and in the tooth space between the cogs (Fig. 3b).

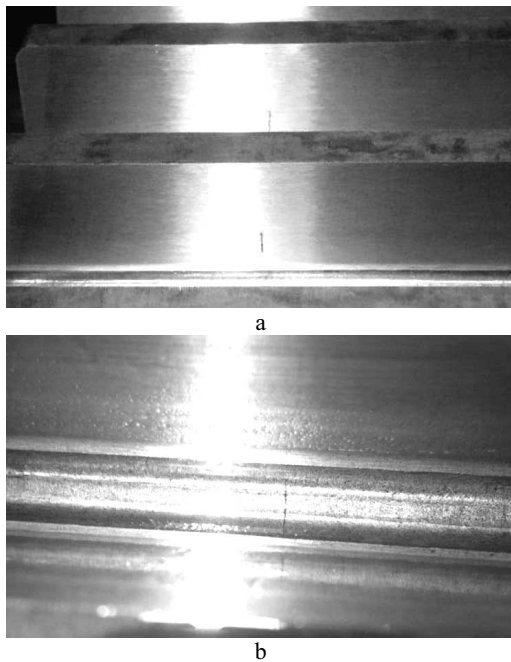


Fig. 3. Discontinuities in a metal blanks: a – on the working surface of the cog, b – in the tooth space between the cogs

Experimental verification has shown internal lack of adhesion, revealed with ultrasonic impulse echo technique in the axial direction. That gear (Fig. 3a, b) does not meet the requirements of GOST 30803, so not admitted in the operation as non-responsive product. A second example of unacceptable defect of metal on the working surface of gear's cog, which also was not admitted in the operation is shown in Fig. 4.

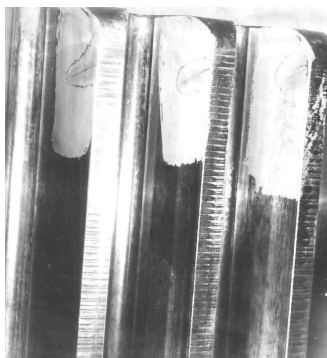


Fig. 4. Unacceptable defects on the working surfaces of the adjoining cogs

Was found that discontinuities in the metal blank manufacturing tooth crown can be observed from the end face of the teeth (Fig. 5).



Fig. 5. Face plane of the locomotive gear with a visible defects

However, internal discontinuities in metal can't be connected to the surface and will not be detected visually. It is known that discontinuities are the stress concentrators and may cause a destruction of the locomotive gear in operation.

To avoid getting the final processing steps and into operation gears with unacceptable defects the metal blanks must be checked by non-destructive testing methods. On railway transport is widely used ultrasonic testing. The effectiveness of ultrasonic testing is largely dependent on the correct choice of the method of testing. So, the most common method of ultrasonic testing - ultrasonic impulse echo method requires to know the location of the expected discontinuity of the metal.

The ultrasonic impulse echo method is based on the registration of echo signals from the discontinuities of the metal and their analysis. Arrival time of the impulses from the discontinuities to the ultrasonic transducer depends on the depth of its occurrence. The geometric shape of the surface of the ultrasonic transducer must be simple and allows moving the transducer while testing process. The analysis of internal discontinuities of metal of locomotive gears showed that they are planar. The optimal condition for receiving ultrasonic echo signal by the ultrasonic transducer is the case where

the acoustic axis is incident on the reflecting surface discontinuity at a right angle. It was noted earlier that the discontinuities of metal blanks of locomotive gears are planar. The amplitude of the echo signal depends on the size of the reflecting surface of the discontinuity and its incidence to the acoustic axis of the transducer.

Let's consider the amplitude of reflection in view of the positional relationship between the ultrasonic transducer and reflector that inclined towards the axis of the transducer at an angle φ (Fig. 6).

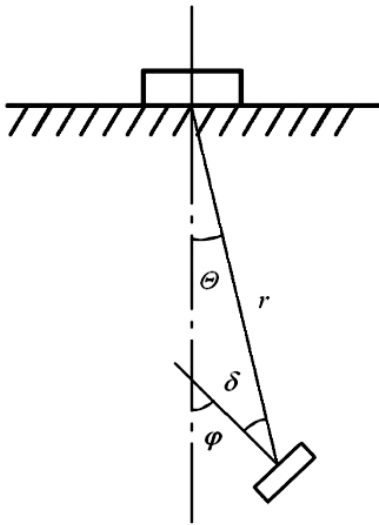


Fig. 6. Calculation scheme of reflection from the inclined defect which is located on the axis of the transducer

For planar reflectors the amplitude of the echo signal depends on the area and the slope of the plane of reflector to the axis of the transducer [28]. The formula for the calculation of the echo signal for the reflector which is located in the far field of the combined transducer with square S_a and size $L_a = 2\hat{a}$ and inclined to the axis of the transducer at an angle φ to the Kirchhoff approximation (fig. 6) has the following form:

$$\frac{P'}{P_0} = \frac{S_a \cdot S_b \cdot e^{-2\Delta r}}{\lambda^2 \cdot r^2} \cdot \cos \delta |R(\delta)| \Phi^2(a\kappa \sin \theta) \Phi'(\kappa b \sin \delta),$$

here: S_b – the square of the reflector,
 S_a – the square of the transducer,

$\delta = \varphi - \theta$ – the angle of incidence of ultrasonic beam on defect,

P_0 – the amplitude of the signal that emitted by ultrasonic transducer,

P' – the amplitude of received signal,

Φ – diagram of directedness of the transducer,

θ – the axis between the direction of echo signal and its projection on the axis of the cylinder,

$r = h / \cos \theta$ – the distance from the surface to the cylindrical reflector,

λ – ultrasonic wave length,

Δ – coefficient of attenuation of ultrasonic wave.

It is known that the surface quality of the ultrasonic input surface should provide its maximum flow in the controlled metal. The increase in the roughness of the surface leads to a decrease in the amplitude of the echo signal and reduces the possibility of detection the lacks of adhesion. Therefore, before the ultrasonic testing is performed the special surface preparation of the forgings, stampings and castings [29] for the purpose of improving the quality of ultrasonic testing. It is recommended to conduct the ultrasonic testing on gear blanks after its mechanical pretreatment to obtain the proper surface quality. Given the fact that a discontinuity of metal of gear blanks have a flat shape and their plane is located in both radial and axial directions, the ultrasonic testing must be performed in the axial and radial directions.

CONCLUSIONS

1. It is shown that the metal surface of the locomotive gears in the manufacturing process can have cracks, which can be detected using the visual inspection methods and magnetic particle method.

2. In locomotive gear blanks may be present unacceptable flat shaped internal discontinuities of the metal which may be both radial and axial directions of the blank.

3. Was grounded the necessity of ultrasonic testing of gears in two directions: axial and radial. To ensure the required

acoustic contact while ultrasonic testing it is necessary to perform the special surface preparation.

4. Ultrasonic testing will prevent getting into the operation gears with unacceptable defects and exclude inputs for further processing steps of defective blanks.

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УЛЬТРАЗВУКОВОЙ КОНТРОЛЬ
НЕСПЛОШНОСТЕЙ МЕТАЛЛА ЗАГОТОВОК
ЗУБЧАТЫХ КОЛЕС ПОДВИЖНОГО СОСТАВА

Павел Колодяжний

Аннотация. Проведен анализ расположения несплошностей металла в заготовках ответственных узлов подвижного состава. Показано, что в заготовках зубчатых колес подвижного состава могут быть недопустимые внутренние несплошности металла, которые имеют плоскую форму, а их плоскости могут находиться как в радиальном, так и осевом направлениях заготовки. Обоснована необходимость ультразвукового контроля зубчатых колес в двух направлениях: осевом и радиальном. Доказано, что проведение ультразвукового контроля позволит исключить попадание в эксплуатацию зубчатых колес с недопустимыми несплошностями, а также исключить затраты на дальнейшие технологические операции бракованных заготовок.

Ключевые слова: заготовки зубчатых колес, несплошности заготовок, ультразвуковой контроль в осевом и радиальном направлении несплошностей плоской формы.