DOI: https://doi.org/10.33216/1998-7927-2025-296-10-29-32

УДК 621.745.55:629.1.01

RESEARCH INTO THE RELATIONSHIP BETWEEN THE STRUCTURE AND COERCIVE FORCE OF SPRING STEELS FOR THE DEVELOPMENT OF A METHOD FOR NON-DESTRUCTIVE TESTING OF ELASTIC SUSPENSION ELEMENTS IN ELECTRIC LOCOMOTIVES

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ДОСЛІДЖЕННЯ ВЗАЄМОЗВ'ЯЗКУ МІЖ СТРУКТУРОЮ ТА КОЕРЦИТИВНОЮ СИЛОЮ ПРУЖИННИХ СТАЛЕЙ ДЛЯ РОЗРОБКИ МЕТОДИКИ НЕРУЙНІВНОГО КОНТРОЛЮ ПРУЖНИХ ЕЛЕМЕНТІВ ПІДВІСКИ ЕЛЕКТРОВОЗІВ

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The research is devoted to studying the relationship between the following characteristics of structural steels used to manufacture suspension springs for freight electric locomotives: hardness, residual deformation and coercive force. The results of testing the elastic elements of electric locomotive suspension for residual deformation under static load have shown that their optimal structure is troostite, which is formed during medium tempering. It is the troostite structure formed during medium tempering of pre-hardened steel that allows obtaining the optimal ratio of elastic characteristics of electric locomotive suspension elastic elements during their operation under alternating loads. The results of experimental studies prove that standard methods of measuring coercive force can be used to control and evaluate the final structure and mechanical properties of the elastic elements of electric locomotive suspension. Given that the quality control of springs for hardness and residual deformation is almost 100%, this allows for a significant reduction in the time spent on control operations. The coercive force of spring steels depends solely on their structural state. If there is a decarburised layer on the surface of the springs, it has practically no effect on the coercive force if the thickness of this layer does not exceed the values established by the applicable regulatory and technical documents. Thus, a slight deviation of the coercive force of the elastic elements of electric locomotive suspension from the optimal values of coercive force established in this study may indicate an excessive thickness of the decarburised layer. The presence of surface cracks on the elastic elements of electric locomotive suspension has no effect on the coercive force. In this context, the nature and mechanisms of crack formation are also irrelevant. The results of the study show that the optimal coercive force of the elastic elements of electric locomotive suspension, which corresponds to their optimal hardness, can only be determined on the basis of preliminary tests of the elastic elements of electric locomotive suspension for residual deformation. The latter parameter is the main operational characteristic of springs, which can be used to determine their suitability for use as elastic elements in electric locomotive suspension systems. The results of the research established a relationship between the structure and residual deformation under static load of elastic elements in electric locomotive suspension systems.

Key words: *springs, residual deformation, coercive force, hardness, troostite.*

Introduction. Magnetic structural analysis is one of the most advanced methods of non-destructive testing of structural materials in modern mechanical engineering [1, 2]. In particular, magnetic structural analysis can be extremely effective in controlling the quality of spring structures. As of today, the most common method of controlling the structure of springs is to measure their hardness. However, in mass production, given the geometry of spring coils, measuring hardness causes certain complications [3]. These complications can be easily overcome by replacing hardness measurement with coercive force measurement. It is known that for most structural steels there is a clear relationship between their hardness and coercive force [4]. This is the basis for the use of magnetic structural analysis for heat treatment quality control [5]. An important factor here is that in order to determine the range of optimal coercive force values, it is necessary to know in advance the range of optimal hardness value.

Requirements for spring hardness largely depend on the conditions of their operation [6]. Even springs made of the same structural steel but designed for different operating conditions may have completely different hardness requirements. It is important to note that different hardness will be determined by different heat treatment modes and, consequently, different structures. According to [6], the main method of mechanical testing of springs is testing for residual deformation under load. All springs with excessively high or excessively low residual deformation under load are rejected. Based on this, it is advisable to establish a relationship between the hardness of springs and their residual deformation under load. This will allow us to clearly determine the range of optimal or acceptable values of spring hardness. After that, it will be possible to experimentally determine the range of optimal or acceptable values of the coercive force of springs. The availability of such data will make it possible to replace the procedure for measuring the hardness of springs and the procedure for testing springs for residual deformation with a much simpler and more convenient procedure for measuring the coercive force.

The objective. This research objective is to develop a procedure for controlling the quality of spring structures by measuring their coercive force, which should replace the procedure for measuring spring hardness and the procedure for testing springs for residual deformation under load.

Research problem. 1. To determine the relationship between spring stiffness and their residual deformation under load. To determine the range of optimal spring stiffness values.

2. To determine the relationship between spring stiffness and their structure in order to determine the optimal spring structure.

3. To determine the relationship between spring stiffness and their coercive force. Determine the range of optimal values for spring coercive force.

Research methodology. Residual deformation was determined on the springs 8TN 281.319 of the suspension of the 2EL5 electric locomotive in accordance with DSTU 1452-96 (fig. 1). The diameter of the spring coils is 42 mm, the material is 58CrV4 steel (EN 10060).

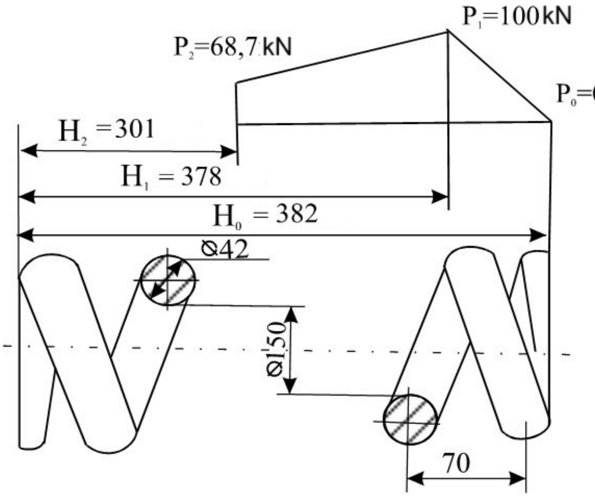

Fig. 1. Diagram of testing 8TN 281.319 springs for residual deformation under load

Residual deformation tests were performed on a P-125 hydraulic press. First, the spring is compressed twice under a load of 100 kN. After the load is completely removed, the height of the spring is measured. The height of the spring after the first test cycle should not change. Then the spring is compressed under a load of 68.7 kN and its height is measured in the loaded state.

A TK-type hardness tester was used to measure hardness, a MIM-8 optical microscope was used to determine the microstructure, and a KIMF-1 coercivity tester was used to measure coercive force.

Results of experimental studies and their analysis. Twenty springs were subjected to a residual deformation test. All springs were hardened in oil at a temperature of 860ºC, followed by tempering at a temperature of 350-450ºC. The absolute deviation of the actual residual deformation of the springs from the nominal value of this deformation (77 mm) should not exceed + 7 mm and -5 mm. At the same time, no residual deformation of the springs is allowed after the load is completely removed. The residual deformation of springs Nos. 1, 6, 12, 15, 19 does not meet the regulatory indicators (table 1). Depending on the magnitude of the residual deformation under load, all springs that have failed the test can be divided into two separate groups. The first group includes springs whose residual deformation under load is less than the lower limit of 72 mm (springs Nos. 6, 19). The second group includes springs whose residual deformation under load is greater than the upper limit of 85 mm (springs Nos. 1, 12, 15).

Table 1

Results of experimental studies

No. of springs	Residual deformation (f), mm	Surface hardness / hardness in the core, HRC	Structure (tempering temperature)	Coercive force, A/cm (before/after removal of the decarburised layer)
1, 12, 15	86 - 88	36 - 38 /35 - 37	Troostite and sorbite (450ºC)	50 - 52/ 50 - 52
6, 19	68 - 71	48 - 50 /47 - 49	Troostite and martensite (350ºC)	68 - 70/ 68 - 70
The rest of the springs	74 - 83	42 - 44 /41 - 43	Troostite (400ºC)	58 - 60/ 58 - 60

Springs with increased residual deformation under static load have relatively low hardness, which corresponds to a troostite-sorbitic structure. Springs with reduced residual deformation under static load are characterised by increased hardness, which is typical of a troostite-martensitic structure. Springs with normal residual deformation values have a hardness corresponding to a troostite structure. Thus, the optimal spring structure, at which the required residual deformation values of springs under static load are achieved, is troostite tempering with a hardness of 41-43 HRC. This structure corresponds to a coercive force of 58-60 A/cm.

In the second stage of the research, the influence of the decarburised layer on the coercive force was analysed. The decarburised layer is formed when the springs are heated during hardening. Its depth depends on the composition of the atmosphere in which the heating takes place. In this study, springs were used that were heated during hardening in air, without the use of any protective gas environment. Under such heating conditions, the maximum depth of the decarburised layer is usually observed, which, nevertheless, does not exceed the values regulated by the current standard (DSTU 1763-98). According to this standard, the depth of the decarburised layer should not exceed 2.5% of the diameter of the rolled product. Springs with a troostite and sorbite structure, in which excessive residual deformation under static load is observed, contain a decarburised layer with a depth of 0.4-0.5 mm (fig. 2). A decarburised layer of the same depth is found in springs with a troostite and martensite structure (fig. 3) and troostite structure. It is characteristic that in all cases, after removing the decarburised layer by grinding, the coercive force remains almost unchanged (table 1). Therefore, it can be reasonably concluded that the presence of a decarburised layer on the surface of springs does not affect their coercive force, provided that the depth of the decarburised layer does not exceed the values specified by the current standard. This means that coercive force measurements can be taken immediately after the springs are released, before they are ground.

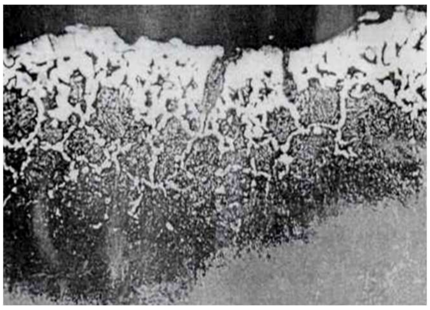

Fig. 2. Decarbonised layer in springs with a troostite and sorbite structure, × 300

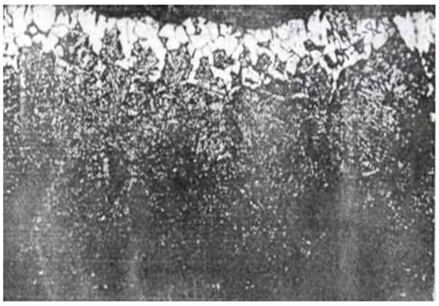

Fig. 3. Decarburised layer in springs with a troostite and martensite structure, × 300

Conclusions. 1. The optimal spring structure, at which the specified values of their residual deformation under static load are achieved, is a troos-tit with a hardness of 41 - 43 HRC.

2. A correlation between the hardness and coercive force of springs has been established. The optimal hardness of springs corresponds to a coercive force of 58 - 60 A/cm.

3. The presence of a decarburised layer does not affect the coercive force of springs if its depth exceeds the values established by the current standard.

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Шевченко О.В., Зінченко Д.М. Дослідження взаємозв’язку між структурою та коерцитивною силою пружинних сталей для розробки методики неруйнівного контролю пружних елементів підвіски електровозів.

Дослідження присвячене вивченню взаємозв’язку між наступними характеристиками конструкційних сталей, з яких виготовляються пружини підвіски вантажних електровозів: твердість, залишкова деформація та коерцитивна сила. Результати випробувань пружних елементів підвіски електровозів на залишкову деформацію під статичним навантаженням дозволили встановити, що їхньою оптимальною структурою є троостит, що утворюються при середньому відпуску. Саме структура трооститу, що утворюється у процесі середнього відпуску попередньо загартованої сталі, дозволяє отримати оптимальне співвідношення пружних характеристик пружних елементів підвіски електровозів при їхній експлуатації в умовах знакозмінних навантажень. Результати експериментальних досліджень доводять, що для контролю та оцінки кінцевої структури та механічних властивостей пружних елементів підвіски електровозів можна використовувати стандартні методи вимірювання коерцитивної сили. З урахуванням того, що контроль якості пружин за твердістю та залишковою деформацією є майже стовідсотковим, це дозволяє суттєвим чином скоротити витрати часу на контрольні операції. Коерцитивна сила пружинних сталей залежить виключно від їхнього структурного стану. Якщо на поверхні пружин є наявним зневуглецьований шар, він не чинить практично ніякого впливу на коерцитивну силу, якщо товщина цього шару не перевищує значень, встановлених діючими нормативно-технічними документами. Таким чином, незначне відхилення коерцитивної сили пружних елементів підвіски електровозів по відношенню до оптимальних значень коерцитивної сили, встановлених у цьому дослідженні, може свідчити про понаднормову товщину зневуглецьованого шару. Наявність поверхневих тріщин на пружних елементах підвіски електровозів не чинить жодного впливу на коерцитивну силу. В цьому контексті також не мають жодного значення природа та механізми утворення тріщин. З результатів дослідження витікає, що оптимальна коерцитивна сила пружних елементах підвіски електровозів, яка відповідає їхній оптимальній твердості, може бути визначена лише на основі попередніх випробувань пружних елементах підвіски електровозів на залишкову деформацію. Останній параметр представляє собою основну експлуатаційну характеристику пружин, за якою можна визначити можливість їхнього використання в якості пружних елементів підвіски електровозів. За результатами досліджень встановлено взаємозв’язок між структурою та залишковою деформацією під статичним навантаженням пружних елементів підвіски електровозів.

Ключові слова: *пружини, залишкова деформація, коерцитивна сила, твердість, троостит.*

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Стаття подана 17.11.2025.