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ENSURING THE OPERATIONAL RELIABILITY OF ELASTIC ELEMENTS BY ACOUSTIC METHODS

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Machine plants place a great deal of emphasis on evaluating the quality of the materials they use and predicting the service characteristics of their finished products. The quality of these materials is usually checked by time-consuming visual inspection of selected batches, and the results that are obtained are not always reliable. It is also important to be able to predict the quality of finished products over time (determine the products' properties during their use). The properties of products used in machine construction are normally predicted by using destructive methods based on the results obtained from evaluating a chosen batch of products, which is energy-consuming and entails high labor costs. A method based on the recording of acoustic emission signals is proposed here for checking incoming materials. The method makes it possible to expeditiously assess the conformance of the materials to the requirements on the manufacturer's certificate and determine if they are free of unacceptable defects.

Keywords: *aerothermoacoustic treatment, acoustic emission, spring steel, acceptance testing, production process.*

To sustain the continuing growth of the military-industrial and space industries in the Russian Federation, it is important to develop new types of technologies that can improve existing equipment and its components. Making the equipment and components more efficient and stabilizing their tactical-engineering characteristics requires the creation of new algorithms, software packages, mechanical and electromechanical systems, and control systems that can be used in the manufacturing process. Almost every element of mechanical and electronic systems and systems used in the space industry is equipped with an elastic element to store energy, damp vibrations, transmit tensile or compressive loads to other elements of various components and parts of machines, absorb shocks during transport, or perform other functions. The heightened requirements that have been introduced for the performance of elastic elements in new products are in turn tightening the requirements established for the technologies used to make machine parts and the methods used to check those parts' service properties.

The operational reliability of elastic elements made of spring steels can be assured by the following: having manufacturers that make elastic elements perform real-time monitoring of incoming materials for compliance with their certificates without it being necessary to use a wide range of different types of specialized lab equipment; the use of nondestructive methods to predict the main service properties of springs over long periods of service (25–30 years), with the methods making it possible to check each spring in a given batch and check the thermal and thermomechanical treatment regimes without having to make control specimens in order to reliably determine the microstructure of each product; the use of combination methods (aerothermoacoustic treatments) that can make real-time changes to the microstructure of raw materials or finished products.

Monitoring incoming materials is necessary to detect unacceptable discontinuities, cavities, and cracks on the surface and inside rolled products in accordance with the certificate specifying the product's chemical composition, mechanical properties, and microstructure. The parameters that characterize the quality of the initial materials are determined at the manufacturer's

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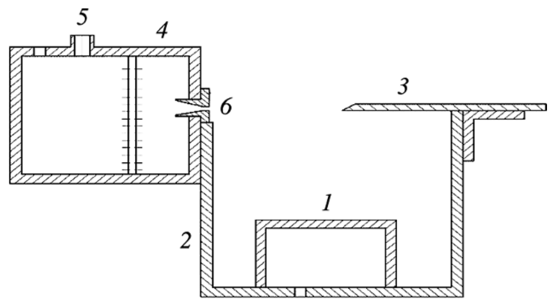


Fig. 1. Sketch of the gas-jet sound generator (GSG): *1*) semifinished product; *2*) resonator; *3*) wedge; *4*) receiver; *5*) union; *6*) nozzle block.

TABLE 1. Mechanical Properties of Steel 65G after the Standard Heat Treatment and Additional ATAT

Treatment regimes after quenching from 830°C		Hardness, *HRC*	σ_u, MPa	$\sigma_{0.2}$, MPa	δ, %	Ψ, %
tempering, °C	additional treatment					
340–360*	–	44–49	1490	1220	5	10
470–510*	–	31–35	981	785	8	30
470	– / ATAT1	44 / 50	1365 / 1660	1280 / 1590	7 / 8	30 / 30
	– / ATAT1	45 / 51	1410 / 1660	1320 / 1590	7 / 8	30 / 30
	– / ATAT2	29 / 38	910 / 1160	790 / 1030	7 / 8	30 / 30

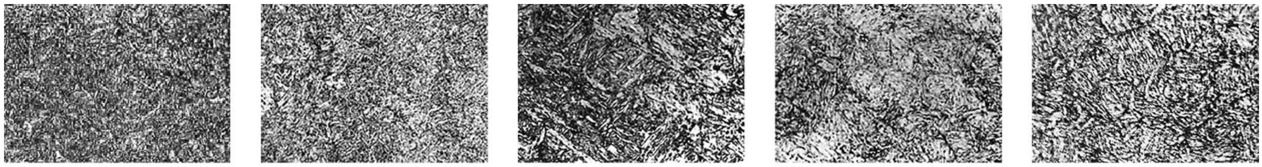
* Heat treatment under factory conditions.

plant by existing methods (tensile tests, preparation and study of metallographic sections, chemical analysis). Cracks are found by ultrasonic flaw detection, but certain features of this technology preclude its use for checking the quality of thin sheets and wire with dimensions smaller than 3–4 mm. Thus, it is important to find a solution to the problem of thoroughly checking the quality of incoming materials and to develop a nondestructive method of evaluating the quality of wire and thin sheet and strip.

A new method which uses acoustic emission has been invented and patented to predict the relaxation resistance of disc springs made of titanium alloy VT23 [1]. Another method has been developed for evaluating the quality of spiral springs made of alloy VT23, and research is continuing on creating test methods for other types of springs made of different materials (spring steels 65G, 60C2A, 65C2BA, etc.). One topic that is of interest from a manufacturing standpoint is determining the relationships between acoustic-emission parameters and the microstructure of raw materials and finished products (springs made of spring steels 65G, 60C2A, and 65C2BA).

Study on improving the quality of raw materials for the production of elastic elements by using aerothermoacoustic treatment (ATAT). The problem of phase changes in the microstructure of raw materials and finished springs is extremely important, but the literature contains almost no results from studies of different methods (magnetic, ultrasonic, etc.) of modifying the microstructure in order to obtain the prescribed physico-mechanical characteristics. At the Baltic State Technical University VOENMEKh, Professors V. N. Uskov and G. A. Vorob'ev are conducting research on the use of a combination ATAT method on wrought alloys [2, 3]. Among the special equipment needed for ATAT is a gas-jet sound generator (GSG). The parts being treated are cooled the generator's resonator (Fig. 1). Springs are subjected to heating and holding at a prescribed tempering temperature, and their subsequent cooling to −10°C takes place while they are exposed to a flow of gas and an acoustic field in the sonic frequency range. The level of acoustic pressure is within the range 140–160 dB.

The standard heat treatment (SHT – quenching from 830°C, cooling in oil, tempering at 470°C for 60 min, cooling in air) used for steel 65G employed in the production of springs and other products does not provide the necessary level of



a *b* *c* *d* *e*

Fig. 2. Microstructure of the steel after the standard heat treatment (SHT) and aerothermoacoustic treatment (ATAT): *a–d*) quenching, tempering at 510°C, 1.5 h (*a*, *b* – ×600; *c*, *d* – ×1000); *e*) ATAT during tempering at 470°C, 1 h after quenching, ×600.

TABLE 2. Recording of Acoustic-Emission (AE) Signals

Specimen	Compressive force F, kN	Number of AE pulses N_i during the ith compression			Total number of AE pulses $N_{tot.72}$
		N_1	N_2	N_3	
TP No. 1	10	347	183	227	17
TP No. 2	10	11034	2541	955	1
TP No. 8	10	2274	971	438	3

TABLE 3. Results of Cyclic Tests and the Amounts of Relaxation

Specimen	$P_{initial}$, kN	$P_{final,}$ kN	Relaxation R, %
TP No. 1	47.43	45.08	4.95
TP No. 3	46.67	47.06	0.84
TP No. 8	45.18	44.57	1.35

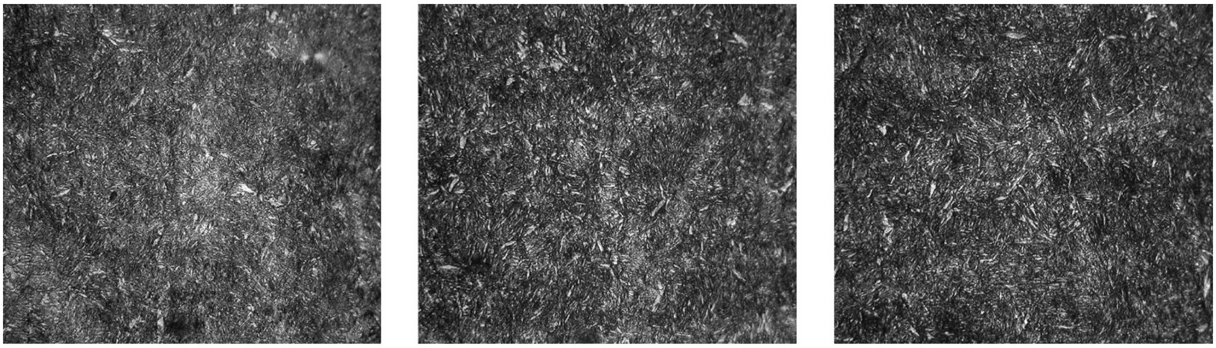
mechanical properties and often results in their broad scatter. To eliminate the scatter of the properties and elevate their values, we studied the feasibility of using two ATAT regimes as the additional treatment. The regimes differ in the preheating temperature: 350°C for ATAT1 and 280°C for ATAT2. Tempering time is 60 min for all the specimens.

It is apparent from the results (Table 1) that ATAT used as an additional treatment after SHT increases $\sigma_{0.2}$ without lowering ductility, which allows elastic elements and machine parts to operate in a reliable manner. To determine the effect of ATAT on the mechanism responsible for forming the structure of the steel, we studied its microstructure after SHT and ATAT. The microstructure was examined during cooling of the steel when it was subjected to tempering after quenching (Fig. 2). The use of ATAT with tempering ensures the formation of a more dispersed structure and a uniform phase distribution, which increases strength without lowering ductility or toughness.

Study of finished products (disc springs made of steel 60C2A – specimens TP-1, TP-2, and TP-3) *by the method of acoustic emission*. The springs were heat-treated by the following regime: quenching (heating to 860, cooling in oil) + tempering at 420°C for 60 min. In the course of the springs' fabrication they were subjected to triple compression and vibration while acoustic-emission (AE) signals were recorded (Table 2) [4, 5].

After the springs' brief compression and vibration and recording of the AE signals, we subjected them to cyclic loading within the range of working loads and then evaluated their relaxation (Table 3) and studied their microstructure (Fig. 3).

The microstructure of disc-spring specimens Nos. 1, 3, and 8 consisted of temper troostite (see Fig. 3), which for steel 60C2A corresponds to the state after quenching and tempering. The surface of all the specimens was decarbonized unevenly



a *b* *c*

Fig. 3. Microstructure of disc springs made of steel 60C2A (×500): *a*) TP No. 1; *b*) TP No. 3; *c*) TP No. 8.

in the depth direction and consisted of pure ferrite in some locations. The depth of decarbonization reached 0.05 mm – sites where the steel had been transformed to pure ferrite, and 0.1 mm – sites where the steel underwent partial decarbonization. The microstructure of specimen No 1 clearly displayed structural nonuniformity compared to the other specimen, probably as a result of the nonuniform distribution of the concentration of the alloying element. The phase composition of specimens Nos. 3 and 8 corresponded more to the classic microstructure of temper troostite. Indirect confirmation of this was the lower level of the AE signals during vibration and the smaller amount of relaxation that occurred during cycling loading.

Conclusions. The results of the experimental study established that there is a relationship between the AE signals recorded during the vibration of disc springs made of steel 60C2A and their resistance to relaxation (relaxation was $R = 4.95\%$ at $N_{tot.72} = 17$ and $R = 0.84\%$ at $N_{tot.72} = 3$). For springs having a high value for relaxation after cyclic loading, during the stage in which the springs were briefly subjected to "artificial" triple compression the AE signals were unstable during each successive correction $N_1 > N_2 < N_3$.

The use of aerothermoacoustic treatment (ATAT) makes it possible to improve product quality, change the microstructure of the initial material or finished product, modify its properties so that they conform to the specifications, and reduce the scatter of the mechanical properties. The expediency of using ATAT instead of existing heat-treatment methods owes to its energy efficiency and simplicity. The use of results obtained from studies aimed at ensuring the operational reliability of elastic elements and results obtained from ATAT demonstrates the promise of acoustic methods in the production of elastic elements.

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