Maraging steels are used in various branches of engineering because they have high strength, ductility, and good technological suitability. In instrument construction these steels are used for making elastic sensitive elements. The range of application of these steels can be extended if, together with good elastic characteristics, they have good elinvar properties, i.e., small change of the modulus of elasticity or of natural vibration frequency within some temperature range.

It was established [1-3] that when the maraging steels Ni8K9M5T, N21K9M5T are heated to temperatures of the biphase \( \alpha + \gamma \)-region, it is possible to obtain the required elinvar properties (low temperature coefficient of natural vibration frequency (TCF)) in combination with high elastic limit. This is attained by heat treatment under conditions ensuring that 40-50\% nickel-enriched stabilized ferromagnetic austenite is obtained in the steels.

The optimal complex of elinvar and mechanical properties of steel N21K9M5T is attained after hardening from 850-900°C and subsequent aging at 575°C 3 h (in the range 20-100°C TCF\(_{20-100} = -30 \cdot 10^{-6}\) 1/deg, \( \sigma_{0.005} = 1100-1150\) N/mm\(^2\)) [3].

It was of interest to investigate the effect of cold forming and of the content of alloying elements on the elinvar and elastic properties of maraging steels whose chemical composition is presented in Table 1.

The steels were melted in a 10-kg furnace by the vacuum-induction method. The obtained ingots were forged into round rods with 8 mm diameter and square rods with 14 × 14 mm cross section from which the test specimens were made.

One part of the specimens was hardened from 950°C, the other part was cold-rolled with reduction of 30, 50, and 70\%. After such treatment the structure of the steels contained 30\% residual nonferromagnetic austenite; to transform it into martensite, the specimens were cold-treated at \(-196^\circ\)C. After aging at 480-675°C 3 h we determined their mechanical properties (\(\sigma_{0.005}, \sigma_{0.2}, \sigma_U, \delta, \psi\)). The TCF was determined from the change of the natural vibrations of the specimen in electromagnetic excitation on an installation "Elastomat 1.024" when heated from 20 to 100°C. The temperature coefficient of the modulus of elasticity (TCME) is correlated with the TCF by the following dependence: TCME = 2TCF - TCLE (where TCLE is the temperature coefficient of linear expansion). The amount of stabilized austenite after heating to different temperatures was determined by the X-ray diffraction method with the use of iron \(K_\alpha\)-radiation.

The morphology of the forming crystals of austenite and the structure of the strengthening phases in heating to the biphase \( \alpha + \gamma \)-region were investigated by the method of electron microscopy.

First we studied the effect of the reduction in cold forming of martensite of the investigated steels on the thermoelastic and mechanical properties in the subsequent aging.

### Table 1

<table>
<thead>
<tr>
<th>Steel</th>
<th>Content of elements, %</th>
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<tbody>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>N23K9M5T</td>
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</tr>
<tr>
<td>H23K9M5T1</td>
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</tr>
<tr>
<td>N23K9MST1</td>
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</tr>
<tr>
<td>N24K9MST2</td>
<td>0.03</td>
</tr>
</tbody>
</table>

*Deceased.*
The results of the experiments showed that preliminary cold forming with ε = 30, 50, and 70% has no effect on the amount of stabilized austenite, and consequently on the TCF in subsequent aging at 575-625°C, but brings about a considerable increase of the elastic limit (σ0.005) and other mechanical properties.

Intense strengthening occurs after total reduction of 30% and increases additionally after deformation with ε = 50%. When reduction is further increased to 70%, strength does not increase any more.

The improvement of the mechanical properties of the investigated steels as a result of preliminary deformation is due to the increased dislocation density and to processes of strain-aging, to increased dispersity of the segregating intermetallic phases.

The results of the investigation of the effect of isochronous heating of hardened and deformed steels in the range 400-625°C on the TCF and on σ0.005 are presented in Fig. 1. Aging of martensite at 400-500°C brings about an increase of the elastic limit because of the formation of finely disperse intermetallic phases. At higher aging temperatures the process of formation of γ-phase (Ar = 520°C) begins, and in consequence the increase of the elastic limit is slowed down and the TCF begins to increase. After aging at 560-600°C the amount of austenite in the structure is 45-60%, TCF20-100 = (-20-+10)·10^-6 1/deg. At the same time the elastic limit decreases and amounts to 800-900 N/mm², like with hardened steels. A further rise of the aging temperature brings about a loss of strength of the steels in consequence of the increased amount of the less strong γ-phase in the structure, coagulation and coarsening of particles of the strengthening phases.

The investigations showed that an increase of the amount of nickel with unchanged titanium content (steel N23K9M5T) leads to a loss of strength and lower elastic limit because of the reduced specific share of the intermetallic phase based on Ni and Ti.

The titanium content has to be maintained within a certain range so that the formation of intermetallic phases does not cause a reduction of the concentration of nickel in the solid solution, and in consequence, an impairment of the elinvar property of the steels.

After deformation and aging at 575°C 3 h, σ0.005 = 1100 N/mm², TCF20-100 = -50·10^-6 1/deg for steel with 1.4 Ti, and σ0.005 = 1100 N/mm², TCF20-100 = -10·10^-6 1/deg for steel with 1.4% Ti.