High-speed steels are at present, like in the past, the chief material for making metal cutting tools: the amount of these steels produced in the entire world is about 220,000 tons [1], which is many times more than the combined output of hard alloys, cermets, and superhard synthetic materials.

Since tungsten is the principal alloying component of high-speed steels and hard alloys, on whose production about 60% of all the tungsten output is used, it is only natural that researchers give much attention to this question and that there is a steady increase of research aiming at the devising of tool steels containing no tungsten or only a reduced amount of it since tungsten is among the metals that are in short supply and most expensive, too [2]. This problem aroused the greatest interest in the years 1937-1941 and 1975-1985.

On the other hand, in consequence of the more demanding and variegated operational conditions of tools, especially when used in automated highly productive machinery and for cutting badly machinable materials, high-speed steels have to satisfy ever more stringent demands on their general and their technological properties. Among the former are hardness and heat resistance (red hardness) whose level determines the cutting speeds, and also strength and impact toughness on which feed, depth of cut, and the possibility of using the tools for intermittent machining depend.

The hardness and heat resistance of high-speed steels are the greater, the higher the content of tungsten, molybdenum, and vanadium in the solid solution after hardening is; in that case during tempering a large amount of strengthening carbides of the alloying components segregates from the solid solution, and the steel becomes very hard and heat resistant.

The strength and impact toughness of high-speed steels are the greater, the finer the grains of the solid solution (of the austenite) are after hardening.

When the hardening temperature is raised, hardness and heat resistance of the steel increase as a result of increased alloying of the solid solution, but strength and toughness are impaired in consequence of the coarser grain.

Whereas the basic properties of high-speed steels determine the level of the cutting properties of the tools, their technological properties, i.e., grindability, resistance to overheating, decarburization and oxidation, ductility in the hot and cold states, have a substantial effect, not only on the efficiency of industrial production of the tools, but also on the stability of the principal properties, and consequently on their reliability; this is particularly important in automated production including GAP [possibly hydraulic-assisted automated production].

Since the most important properties of high-speed steels depend on their content of tungsten, molybdenum, cobalt, and vanadium, it must be assumed that the driving force behind the development of present-day high-speed steels is the resolution of the contradiction between the necessity of large and increasing output of these steels with a high complex of basic and technological properties on the one hand, and on the other hand the possibility of implementing such production under conditions of short supply and high price of tungsten and cobalt, and also of molybdenum and vanadium.*

However, in spite of numerous and extensive investigations [4-7], until recently not one kind of steel was in effect suggested which, with lower overall content of tungsten and molybdenum than steel 86H5, had the same or at least a sufficiently good complex of

*The cost of 1% W, Co, Mo, V, and Fe in 1 ton of cast high-speed steel is 285, 294, 166, 104, and 0.72 rubles, respectively [3].
basic and technological properties: at present steel R6M5, like steel R18 in the past, is everywhere the principal high-speed steel.

The above-said and the main content of the present article refer to high-speed steel produced by the conventional metallurgical procedure, and they do not touch upon the technology of their production by the method of powder metallurgy which opens up great prospects in the devising of tungstenless high-speed steels (see, e.g., [31]).

It should be recalled that the compositions of the steels R18 and R6M5 were chosen on the basis of results of extensive experimental investigations of the effect of the alloying components and of carbon on the properties of steels, without fundamental theoretical substantiations being provided. This lack of substantiation is apparently to a large extent the reason why up to very recently attempts at finding an equivalent replacement of steel R6M5 by steels with low content of alloying components were unsuccessful. In its turn, the limited role of theory in this respect is undoubtedly a consequence of the fact that high-speed steels constitute one of the most difficult objects of investigation in metal science because of the complexity and variety of the transformations proceeding in them both during primary crystallization and in the solid state, the large number of phases participating in these transformations, and also because of the stringent requirements that various properties of these steels have to fulfill.

It is therefore important to establish the reason why the compositions of the classical high-speed steels R18 and R6M5 (containing 1 and 2% V, respectively) are up to the present the best among many other devised compositions of high-speed steels with ordinary heat resistance.

First of all the coinciding results of [8, 9] should be pointed out; these authors studied the phase composition and the structure of the carbides in the alloys belonging to the system Fe-W-C in dependence on their tungsten and carbon content. Kraflner [8] assumed that the composition of R18 was most successful because an increase of tungsten to 18% in an alloy with 0.7-0.8% C leads to the formation of a carbide phase consisting solely of the binary iron carbide and tungsten type $M_4C$ of the composition $Fe_4W_2C$ (Fig. 1a) (in the opinion of Unaniskii and Chebotaev [9] $Fe_2W_2C$) which "is the carrier of the heat resistance of high-speed steels" [8]. It should be noted that when steel contains 0.7-0.8% C, the minimally permissible hardness level HRC 60-62 is ensured in metal cutting tools.

It is significant that the vanadium content of steel R18 initially did not exceed 0.2%.

It was established [10] that in steels containing about 0.8% C and 1.5-2% V (with approximately 4% Cr), the binary carbide $Fe_4(W, V)_2C$ becomes the principal carbide.