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Title: The Problem of Wall Stress and Flame-Tube Metal Behavior In Gas-Turbine Combustion Chambers Under Operating Conditions USSR Ya. S. Gintsburg.

Source: Energeticheskiy Byulleten', No 2, 1950, pp 26-29.

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THE PROBLEM OF WALL STRESS AND FLAME-TUBE METAL BEHAVIOR IN GAS-TURBINE COMBUSTION CHAMBERS UNDER OPERATING CONDITIONS

Ya. S. Gintsburg

N. N. Kurochkin, in his article, "Concerning Temperature Stresses in the Metal of Gas-Turbine Combustion Chambers" [cf. FDD Per Abs 1621247], examined a partial case of the determination of heat stresses in the walls of flame tubes of gas-turbine combustion chambers, such stresses being the result of nonuniform temperature distribution over the thickness of the wall. As a result of the analysis of the phenomena occurring in the walls of the flame tube an hypothesis was expressed concerning the relaxation of the stresses. This hypothesis might possibly give rise to an erroneous idea that the flame-tube walls, in the process of operation, are spontaneously relieved of heat stresses. Actually, the conditions involved in the generation of these stresses, and their effect on the strength and service life of the flame tube are considerably more complex.

Temperature distribution in the flame-tube walls is nonuniform not only with respect to their thickness (as a result of the difference in the temperatures of the gas current and secondary air which reaches the outer surface of the flame tube), but also with respect to their circumference and length. Due to the eccentric location of the flame the walls of the flame tube may not be heated evenly around the circumference. The accumulation of coke dust on the outer surface of the tube brings about cases of local overheating which may lead to the appearance of gradients up to 600 - 650°. The nonuniformity in the heating of the walls of the shell of the flame tube by the flow of gas with respect to flame-tube length, with a diameter of 400 - 800 mm, may amount to 200 -300°.

Therefore, local temperature stresses may actually exceed by many times the stresses as calculated by Kurochkin.

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The existence of the above-mentioned temperature gradient unavoidably gives rise to nonuniform deformation in the walls in the various temperature zones. The lower the heat conductivity of the wall-metal the higher will be the temperature gradient and the greater will be the difference in the amount of deformation in the variously-heated zones of the shell. It should be emphasized that the size of the temperature gradient is directly proportional to heat conductivity and, to a lesser degree, depends upon the reflective and emission property of the outer surface of the walls of the tube, radiation loss, and other factors. Experiments specially established for flame-tube models showed that with constant flame temperature and configuration, the maximum temperature gradient with respect to the length of a shell made of alloys with low heat conductivity may amount to 800°, as against 200-250° in the case of shell made from alloys with a relatively high heat conductivity.

Similarly, a more highly heated length of the shell of the flame tube of the combustion chamber, i.e., localization of heating along the length of the shell, also depends upon the heat conductivity of the alloy contained in the shell. The ratio of the more highly heated length to the total length of the shell characterizes the degree of tube-profile distortion due to nonuniform deformation. At the same time the localization of heating increases as scale formation, oxidizability, and tendency to fusion of the alloys' grain boundaries increase.

In the case of repeated action of the heat (cyclic heating) on flame tubes subject to localized heating in the presence of a considerable temperature gradient, the phenomena of so-called thermal fatigue arise. Thermal fatigue is very clearly expressed in the case of combustion chambers for aircraft gas turbines in which periods of forced operation alternate with idling periods. The phenomena of thermal fatigue lead to the formation of ring cracks and the breakdown of the flame tube. The initial period of thermal fatigue is connected with buckling phenomena, which are followed by crack formation.

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Measures for increasing the heat conductivity of tube material are a contributing factor in the reduction of the temperature gradient. Figure 1 shows the heat-conductivity values for alloy 20-75. It is evident here that the coating of copper considerably increases the heat conductivity of low heat-conductive alloys. In addition, attempts were made to increase heat-resistance and lower scale formation by coating with chromium and nickel. Table 1, below gives examples of the increase in resistance to thermal fatigue when the above-mentioned electrolytic coatings are used.

Table 1. The Effect of an Electrolytic Coating on Thermal Fatigue

Alloy	Thickness of Sheet (in mm)	Number of Cycles Before Deterioration		
		Without coating	Type of coating	With coating
13-8	0.84	20-80	Cu - Ni	50-150
19-9Ti	0.81	30-100	Cu - Ni	20-250
19-9Nb	0.81	100-130	Cu - Ni	50-350
	0.76		Ni	220-700
		50-220	Cu	750-1370

Efforts to eliminate deformation (buckling, crack formation) may also include an increase in the wall-thickness of the flame tube. Examples of a reduction in the tendency towards thermal fatigue when this method was applied to an experimental flame tube are presented below in table 2. A decrease in local deformation may also be obtained by lowering the coefficient of thermal expansion through selection of alloys of suitable composition and coating with heat-resistant materials. However, it should be noted that in order to lessen crack formation due to thermal fatigue and increase length of service, a comparatively small increase in heat conductivity or a great increase in the permanence of resistance to oxidation and an increase in the coefficient of thermal expansion are sufficient.

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Phenomena of local deformation may also be aggravated by aging phenomena in heat-resistant alloys. A substantial decrease in the volume of heat-resistant alloys as a result of the precipitation of dispersed phases are observed in the aging process. The character of a similar change in volume with time in the case of a highly heat-resistant Cr-Ni-Fe alloy is shown in Figure 2. The effect of the temperature gradient in this direction may also be viewed as the result of the varying decrease of metal volume in the variously-heated zones of the flame tube.

Table 2. The Effect of Sheet Thickness on Thermal Fatigue

Alloy	Thickness of Sheet (in mm)	No of Cycles Before Deterioration
18-8	0.84	30-60
	1-60	150-250
19-9Nb	0.63	50-100
	0.84	50-200

The problem of the effect of all the above-mentioned local and overall heat stresses on structural strength, whether thermal fatigue phenomena are absent or present, is related to the mechanical strength of the material used in the flame tube. However, it should be noted that calculation has to be performed according to the quantity of the alloy's conventional yield point at operating temperature and not according to the elastic limit, which generally is not observed in alloys when working in the field of high temperatures.

The resistance to creep of the heat-resistant alloys generally used for flame-tube shells in combustion chambers is very low at the operating temperatures for the flame-tube walls. Table 3 gives the creep limit of some commonly-used alloys with total attainable deformation of 1% for 10,000 hours. With attainable deformation of 1% for 100,000 hours, the creep limit at these

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temperatures is practically equal to zero. For this reason, even with minimum calculations and thermal stresses, some creep will certainly be evident. Under conditions of cyclic heating the creep phenomenon will aggravate local deformation (due to the presence of the temperature gradient) and, by the same token, will increase thermal fatigue and shorten the flame tube's service life. In addition to the above-mentioned factors, the following requirements must also be considered when selecting the material for the flame tube.

The alloy for the flame tube must be as stable against intercrystalline corrosion as possible, particularly in welded joints. Intercrystalline corrosion may occur as a result of the condensation of flue gases in a non-operating portion of the gas turbine, particularly in the case of a low air temperature.

The alloy must have sufficient resistance to gas corrosion from flue gases at flame-tube operating temperatures. Figure 3 illustrates the relative stability of three alloys in the combustion products of a gas turbine.

Table 3. Creep Limit (1%, 10,000 hrs)

Alloy	Temperature (in °C)	Creep Limit (in kg/sq mm)
25-12	815	0.8
25-20	815	0.7
15-35	815	1.4
15-35	870	1.0
20-75	815	1.4
20-75	870	1.0

Finally, to avoid plasticity losses, the alloy must have a sufficiently high resistance to carburization from the products of combustion. Figure 4 shows a comparison of the carburization resistance of some frequently-used alloys.

/Figures are appended./

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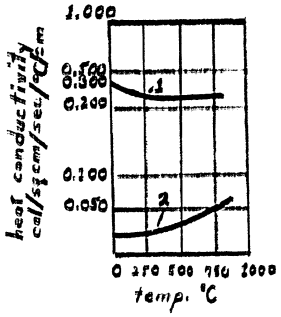

Figure 1: Heat conductivity of alloy 20-75.

1.- without coating
2.- coated with Cu

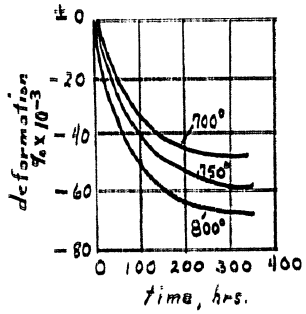

Figure 2: Change in volume during aging.

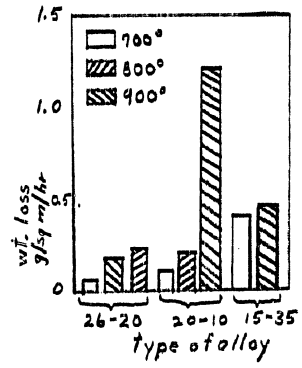

Figure 3: Resistance of three alloys to gas corrosion.

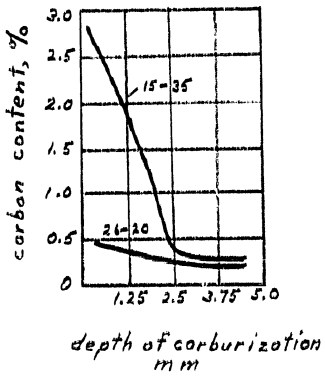

Figure 4: Resistance of two alloys to carburization.

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