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PROBLEM OF AIR-COOLING GAS TURBINE BLADES

K VOPROSU O VOZDUSHNOM OKHLAZHDENII LOPATOK GASOVYKH TURBIN

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Problem of air-cooling gas turbine blades

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In order to improve the specific thrust of modern aircraft gas turbines, solutions must be found to a series of problems; one of the most important arises from the raising of gas temperatures at inlet to the turbine.

Scientific research and experimental work, carried out at present with a view to solving this problem are directed towards inventing new heat-resisting materials, towards more efficient design and construction and towards more efficient methods of cooling turbine components working in regions of high gas temperature.

The present paper describes a design, elaborated by the author, of an air-cooled gas turbine blade and the results of preliminary tests carried out to ascertain its reliability.

The construction of the blade (fig. 1) consists of a supporting stem 1 taking the load, a freely mounted profiled cover shell 2 and a thrust collar 3. The supporting stem is made in one piece with the root of the blade. The thrust collar is welded on or stamped on after the cover shell has been mounted in position. There is practically no contact between the supporting stem and the cover shell and the latter can therefore expand freely on heating. Due to the effect of centrifugal forces, the shell is continually subjected to compression, as it bears against the thrust collar 3. All the stresses in the cover shell are conveyed to the "cold" stem.

Fig.1. Diagram of the composite encased blade designed by the author.

The cooling air, as shown in fig. 1, is conveyed through the openings in the root and stem to the inside surface of the shell.

Cooling the shell and the stem on the inside in a chordwise direction, the air is heated and ejected into the flow passage between adjacent blades in the turbine rotor through the openings situated near the trailing edge of the cover shell.

The possibility of free thermal deformation of the shell in a radial (or spanwise) direction and the absence of any solid connection with the stem, tend to reduce the stresses in the structure. The temperature distribution along the spanwise length of a blade of this sort is bound to be more uniform (fig. 2.).

Fig.2. Temperature distribution along the spanwise length of the blades: 1 - uncooled blade, 2 - covered blade with a free cover shell (the stem does not take part in the heat exchange), and 3 - covered blade with a cover shell joined to the stem (the stem takes part in the heat exchange).

The design allows of considerable temperature differences between the cover and the stem and thereby ensures conditions which might allow a less heat-resistant material to be used for the stem.

The factor of safety of the construction as a whole is determined by the factor of safety of the cover shell. With a uniform strength of shell and stem the latter can be considerably lightened. A reduction in the weight of the blade will ease the load on the turbine rotor or will reduce its weight.

Experiments carried out in 1949 at the KAI Turbine Experimental Laboratory (1) with a covered blade of a similar construction, have shown a satisfactory temperature uniformity both along the spanwise length as well as along the chordwise perimeter of the blade (figs. 4 and 3). Fig.5 shows the construction of this blade.

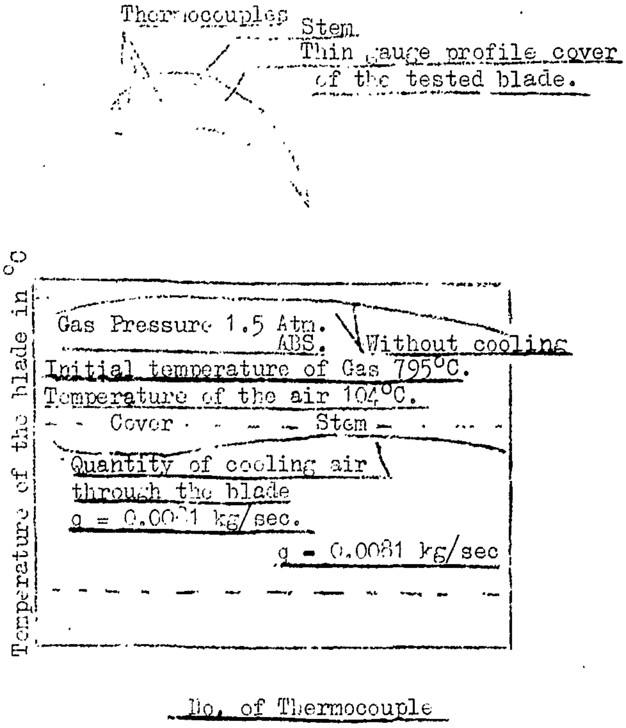

Fig. 3. Temperature distribution along the profile of the composite covered blade [KAI(1) experimental data]

(2 Graphs next page)

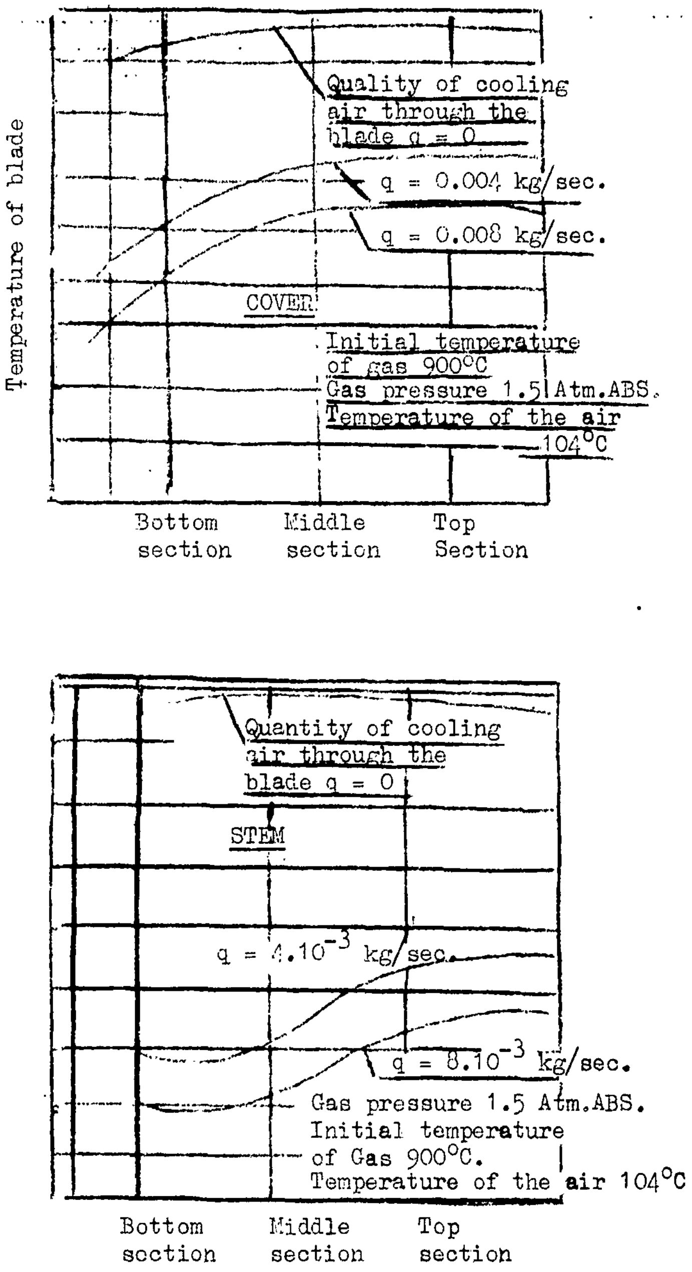

Fig. 4. Temperature distribution along the length of the composite covered blade [KAI(a) experimental data.]

Fig. 5. Diagram of blade designed by the KAI Gas Turbine Council in 1949. (1) supporting stem, (2) thrust ribs and (3) thin gauge cover shell.

Words in figure (top to bottom):
Roller weld
Roller weld
Clearance not less than 1 mm

The disadvantages of this construction are the low efficiency of cooling, due to the radial (or spanwise) disposition of the cooling channels, and the possible warping of the cover casing after welding, which would naturally lead to loss of stability.

The present construction does not possess these disadvantages, since:

(1) the cooling flow of air traverses the cover casing in a chordwise direction, which is more efficient

(2) the cover shell is mounted on the stem already welded i.e. after its heat treatment and after having been already aligned and straightened, which eliminates the possibility of warping, hollow formation, bending or kinking. It can be reasonably expected, therefore, that the present construction will be more efficienct from the heat transfer point of view than the previous one.

The principal distinguishing feature, characterising the present construction, is the fact that the stem of the blade is protected from the effect of the high temperature by the cover casing and by the flow of cooling air,

In previous designs of composite covered blades (for example as in the one shown in fig. 6), the stem of the blade takes part in the heat exchange process, due to the fact that the ribs of the stem are soldered or welded to the cover casing. The increase in the cooling surface thus obtained, brought about a certain decrease in the temperature of the cover casing and a certain increase in the temperature of the stem.

According to our calculations the temperature in the cover shell of a blade of this kind can, due to the transfer of heat to the stem, drop by approximately 10% and the temperature will not be uniform (see fig.2), which will lead to considerable thermal stresses. Calculations have shown that the temperature fluctuations can be of the order of 100°C.

The manufacture of this kind if blade is difficult and the efficiency of its cooling depends not only on α_B and on the heat exchange surface, but also on the reliable contact between the cover and the ribs.

Fig. 6. Diagram of blade, the stem of which takes part in the heat exchange via the longitudinal ribs.

In a construction of this sort it is impossible to use non-heat-resisting materials, even if the turbine entry gas temperature is only moderately high (800°C).

Another special feature, distinguishing our design, is the fact that the whole of the covering shell of the blade is continuously subjected to compression only.

There is as yet no unanimous agreement on the question of the effect of the direction of deformation (compressive or tensile) on the limiting strength of materials at normal temperatures. Thus N.M. Belyaev (2) considers that the values of the limit of proportionality (and also of the yield point for steel) and of the elastic moduli for plastic materials are approximately the same for tension and compression.

I. A. Oding (3), on the other hand, maintains that special features of the metal's structure are often the cause of the metal having a higher yield point in compression and bending than in tension.

It seems obvious that in selecting any specific type of material the choice should be based on experimental data, taking into account the given direction of deformation taking place in the part or section in question.

From the point of view of resistance to deformation at high temperatures, however, the direction of deformation is not unimportant. as at present it is generally accepted that the resistance of a material can be improved by any factor, which will help to decrease the mobility of the atoms along the granular boundaries and increase the inter-atom bonds in the crystal lattice (4).

If the distances between the atoms are increased in tension and decreased in compression, then it is obvious that at higher temperatures the atoms of a metal in tension will possess a higher mobility than those of a metal in compression and the inter-atom bonds in the former case will therefore be weakened.

It is mainly this feature that was taken into consideration in determining the direction of the deformation in the blade cover of the present design.

An increase in the resistance to deformation, even if slight, can often increase considerably the computed stress-rupture life of the construction as a whole.

The SAE journal (5) contains the following interesting data in this connection.

Tests on one of the engines have shown that the computed stress-rupture life of turbine blades can be increased 44 times by decreasing the temperature by 55°C and the number of revolutions by 4%.

Failure of the thin-gauge covering due to compression forces can take place not only for reasons of strength, but also because the cover shell may not retain the shape originally intended for it by the designers, in other words it may lose its stability. For the design therefore to function reliably, it is necessary to ensure not only its resistance to deformation at high temperature but also the stability of all its parts.

In order to test the reliability of the cover casing in conditions of axial compression, a series of preliminary tests were carried out, consisting of static tests at normal temperatures.

Typical cover shells, conforming in shape to present day turbine blades, were used as samples. The lengths of the tested casings ranged from 200 down to 50 mm, with corresponding chord lengths ranging from 40 down to 30 mm. In all more than 200 tests were carried out.

The tests were conducted on Gagarin's standard machine, provided with a special device to minimise any possible bending or buckling. The samples were of light sheet steel material of type 1Kh18N9T, EI696 and EI437, 0.4 to 0.5 mm thick.

Manufacturing details of the cover casings and the methods of heat treatment applied, were worked out preliminarily.

The tests have shown that the coverings cease to be efficient as a result of the combined effect of the overall initial length and the considerable and excessive increase in the deformation of the material at stresses approaching the yield point.

All the tested cover shells showed the characteristic signs of local loss of stability in the form of local buckling, which set in suddenly (fig. 7.).

Fig. 7. Photograph of tested cover shells. The local stability defects are clearly seen.

The maximum critical stresses σ_k causing failure in stability were as follows:*

*Chief Engineers A.A. Kalimullin and R.G. Khairullin of the Turbine Experimental Laboratory took part in the stability tests.

for covers made of EI696 material $\sigma_k = 60$ to 64 kg/mm^2

for covers made of 1Kh18N9T material $\sigma_k = 27$ kg/mm^2.

The yield points in tension for these materials are as follows: for the EI696 material $\sigma_{02} =$ kg/mm^2, for the 1Kh18N9T material $\sigma_{02} = 29$ kg/mm^2. The cover shells made of EI696 material were subjected to ageing, those of 1Kh18N9T material were tested as supplied.

To get a full picture of the characteristics of the given blade design, it is necessary to have some data relating to its efficiency from the point of view of heat transfer. As a first approximation the cooling efficiency of this type of blade can be assessed from the results of the experiments carried out at the Experimental Laboratory in 1949.

Fig. 8 shows test results obtained with this blade.

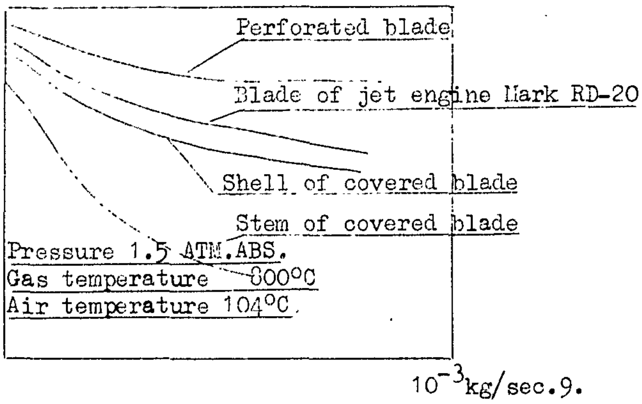

Fig. 8. Experimental data of tests of a covered blade, carried out by the KAI Gas Turbine Council in 1949.

Conclusions

The proposed blade design can be used efficiently in moderately high gas temperatures of the order of 800 to 900°C. It is possible, in these conditions, to make the stem of a non heat-resisting material.

The use of a 'cold' stem will ease the load on the turbine rotor or will reduce its weight.

Endurance tests have shown that cover shells, of the type proposed, can function efficiently in the above design and that there is no reason to anticipate any stability failure.

For a final assessment of the efficiency of the design proposed, it will be necessary to carry out additional tests at higher temperatures, both in static bench conditions as well as in the working conditions of an engine.

To assess the efficiency of the proposed blade, special thermal tests will be necessary.

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Item 1 omitted in Russian text.

2. N.M. Belyaev. Strength of Materials. Fizmatgiz.1959.

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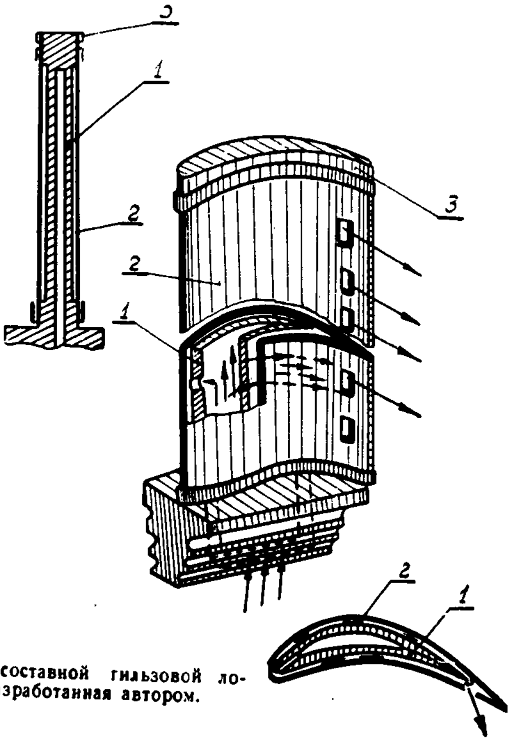
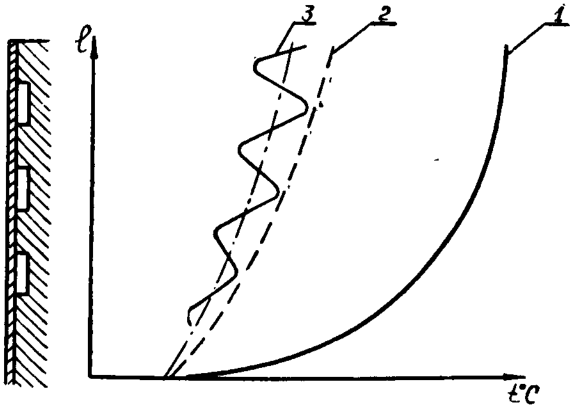
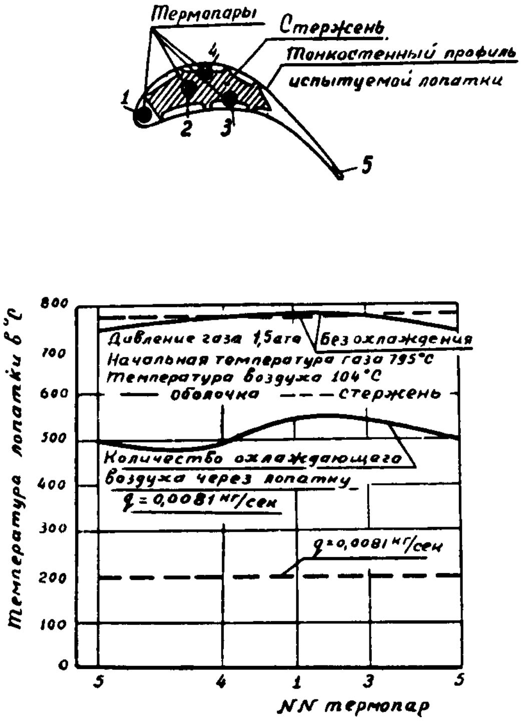


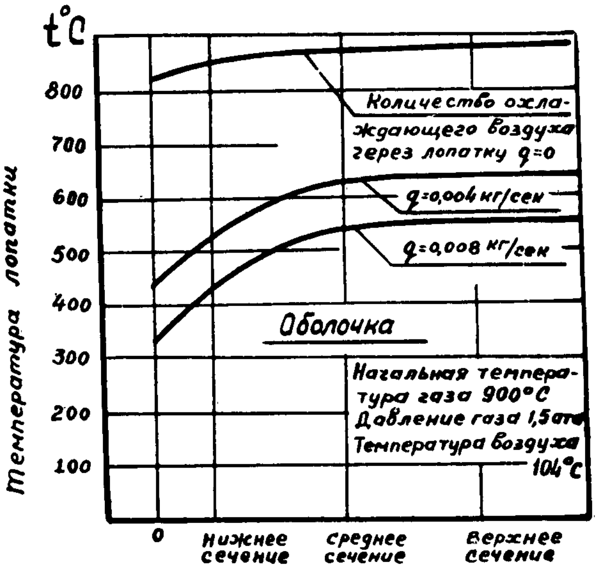
Фиг. 1. Схема составной гильзовой лопатки, разработанная автором.

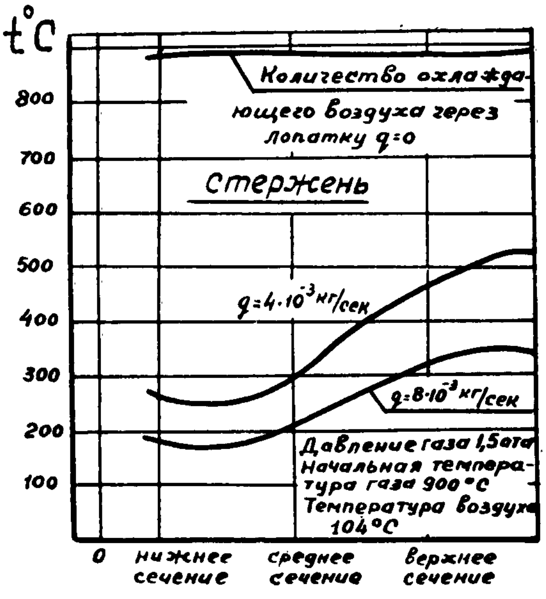


Фиг. 2. Распределение температуры по высоте лопаток: 1 — неохлаждаемая лопатка, 2 — гильзовая лопатка со свободной оболочкой (стержень в теплообмене не участвует), 3 — гильзовая лопатка с оболочкой, соединной со стержнем (стержень участвует в теплообмене).

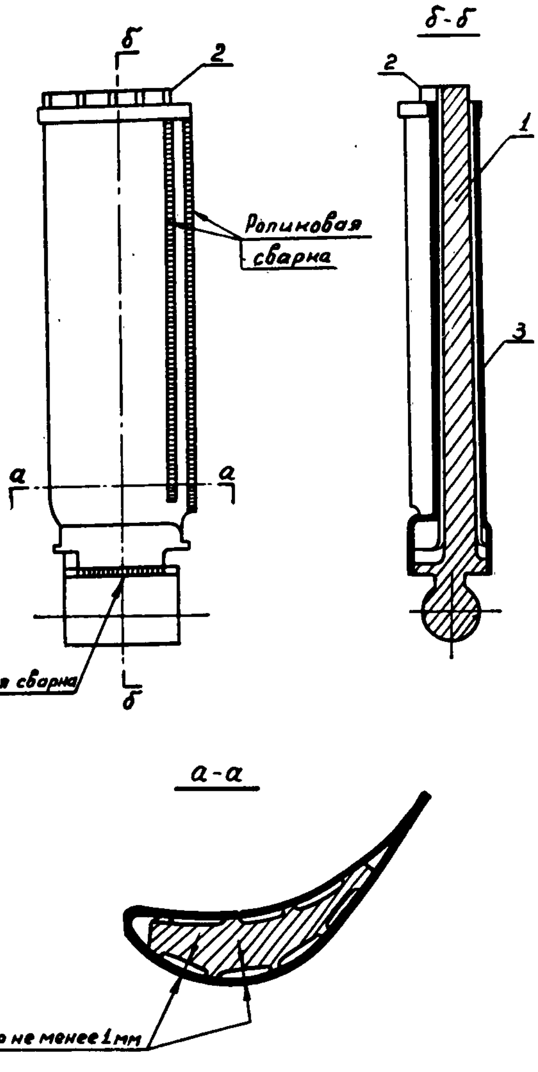


Фиг. 3. Распределение температуры по профилю составной гильзовой лопатки (опытные данные КАИ [1]).

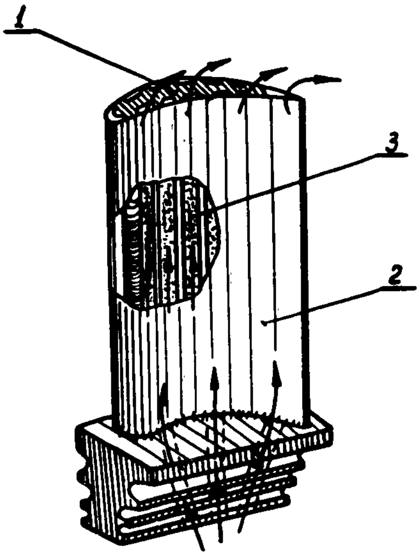




Фиг. 4. Распределение температуры по высоте составной гильзовой лопатки (опытные данные КАИ [1]).

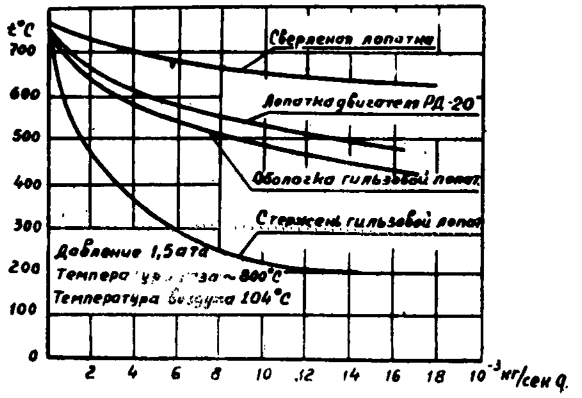


Фиг. 5. Схема лопатки, разработанной кафедрой газовых турбин КАИ в 1949 г.: 1) несущий стержень, 2) опорные выступы, 3) тонкостенная оболочка.



Фиг. 6. Схема лопатки, стержень которой вовлекается в теплообмен через продольные ребра.

Фиг. 7. Фотография испытанных оболочек. Отчетливо видна местная потеря устойчивости.



Фиг. 8. Экспериментальные данные испытаний гильзовой лопатки, разработанной кафедрой газовых турбин КАИ в 1949 г.

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7pp.,4ref.,8fig.

Describes a design of blade in which the profiled "cover" surface surrounds, but is not rigidly secured to a central supporting stem which is integral with the blade root. The external cover is free to expand. All the stresses on the blade assembly are taken by the "cold" stem. Cooling air passes from the blade root, between the stem and cover shell.

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