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# Heat transfer intensification using acoustic waves in a cavity

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ABSTRACT

The presented paper concerns the idea of using a sound wave to intensify the heat transfer in thermally loaded elements of a gas turbine. The general idea of this type of cooling is described and numerical studies are presented. The applied numerical model is validated based on experimental studies. The research is focused on an improvement in cooling of thermally loaded blade corners. A new concept of the vane internal geometry that improves cooling conditions by generating a sound wave and causing unsteadiness in the flow is compared with the currently used solution. Additionally, a conjugate heat transfer analysis is performed, which allows a better validation of the results.



## 1. Introduction

Efforts made to ensure better performance of turbines, an improvement in their durability and reliability and a reduction in their negative environmental impact are the basic driving force behind the development of turbine propulsion systems. Improved performance involves many economic, ecological and functional advantages (smaller consumption of fuel, reduced pollution and an increased range of a means of transport). The efficiency of energy conversion in systems with a gas turbine depends on several factors, the most important of which are the value of the gas temperature at the turbine inlet, the choice of the right compression ratio and the use of an appropriate system configuration.

The hottest issue at the moment that draws enhanced attention in engineering activity is the raising of the turbine inlet temperature, both in stationary and aircraft turbines [1]. The cooling of the turbine components is essential to ensure their appropriate strength and durability. However, supplying the cooling system with air from a compressor involves a drop in the gas turbine efficiency. Therefore, finding a method of a more effective use of the cooling medium flow is a matter of special interest in state-of-the-art design solutions. A correct selection of the cooling system geometry and parameters is a complex and — consequently — a difficult task. Solving it requires a more and more detailed identification of the thermal and flow phenomena for complex geometrical configurations, as well as the use of optimization methods [2]. Experimental testing is widely used to investigate cooling conditions despite the fact that such tests are very expensive and difficult, mainly due to the high temperature and rotation-related phenomena [3,4]. Numerical methods are common in analyses of the thermal and flow problems. In a large number of numerical simulations, especially if they are used for optimization purposes, it is assumed that the phenomena have a steady character [2,5]. This is related to the fact that the computations are very time-consuming. However, if used to simulate the heat transfer conditions, steady- and unsteady-state flow models may give divergent results, e.g. Ref. [6]. Therefore, the effects resulting from the unsteady nature of the occurring phenomena should be taken into account whenever possible. Moreover, inducing the flow unsteadiness improves the heat transfer in many cases and this is the area where a chance to find more effective concepts of the cooling of the turbine components is seen [7]. The research presented herein follows this direction. It concerns the assessment of the impact of unsteady effects caused by the acoustic wave generation on the heat transfer and cooling conditions in places exposed to high temperatures, where convective cooling effectiveness is substantially decreased, e.g. in regions of stagnation or the coolant near-wall reduced velocity in separation zones. It should be

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**Nomenclature**

| | |
|---|---|
| $f$ | frequency, Hz |
| $h$ | enthalpy, J/kg |
| k | turbulence kinetic energy, J/kg |
| $p$ | pressure, kPa |
| $Q$ | heat flux density, $W/m^2$ |
| SPL | sound pressure level, dB |
| $t$ | time, s |
| $T$ | temperature, K |
| $u$ | velocity, m/s |
| $\delta$ | Kronecker delta, - |
| $\lambda$ | thermal conductivity, $W/(m\cdot K)$ |
| $\mu$ | dynamic viscosity, $Pa\cdot s$ |
| $\rho$ | density, $kg/m^3$ |
| $\tau$ | shear stress, kPa |
| $\omega$ | turbulence frequency, 1/s |

*Indices*

| | |
|---|---|
| $b$ | bulk |
| $tot$ | total |
| eff | effective |

emphasized that the acoustic wave can be used in conditions that make it possible to amplify it sufficiently. Achieving an appropriate level of the wave amplification requires selection of appropriate flow- and geometry-related parameters. The presented cooling concept is also the subject of a patent [8].

## 2. Idea of using an acoustic wave to intensify the cooling process

At present, the stator and rotor blades are equipped with a system of internal and external cooling. In the case of closed cooling systems, internal cooling is the only option. An example idea of the internal cooling system solution with a U-shaped cooling channel is presented in Fig. 1. In this case, the place which is most exposed to the effect of high temperature is the blade tip. This is caused by the fact that the flue gas flow through the tip clearance is considerably faster, which is related to the high difference between pressures on the two sides of the blade. As a result, a thin boundary layer is observed in these areas, which translates into a high heat transfer coefficient. The coefficient may be 1.7 times higher than the value on the surface of the blade itself [9].

In this situation, the use of internal convective cooling of the blade tip is difficult. This is related to the appearance of a stagnation region where the conditions of cooling are deteriorated and a substantial increase in the temperature of the working medium and, in consequence, of the blade material occurs. The area is marked in Fig. 1. The use of acoustic disturbances is proposed to intensify cooling in this place. The disturbances will cause an increased level of turbulence and movement of the fluid.

Generally, the acoustic wave may be generated by sources such as mechanical vibrations, the temperature gradient [10–13] or the flow field unsteadiness [14–16]. The last two methods are especially interesting because they do not involve the need to use movable elements generating the acoustic wave.

Fig. 2 presents a concept of the blade cooling system modified according to [8]. In this solution, a number of additional cavities are applied, which – if shaped properly and under appropriate flow conditions – may generate an acoustic wave with a considerable amplitude in the cavities.

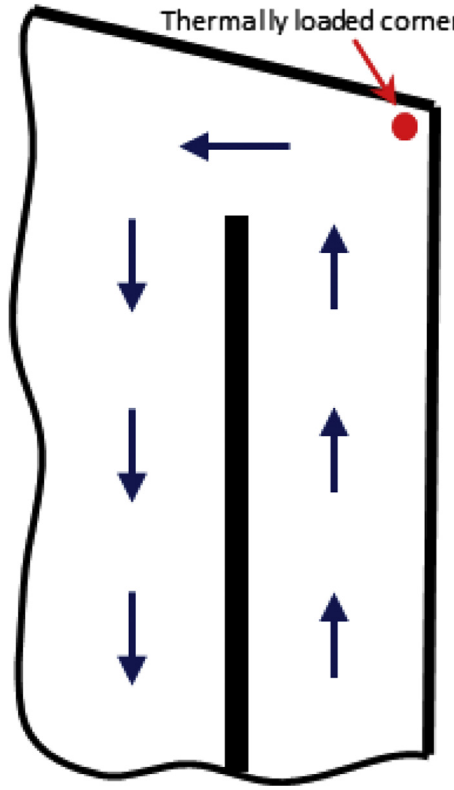


**Fig. 1.** Cooling system used at present.

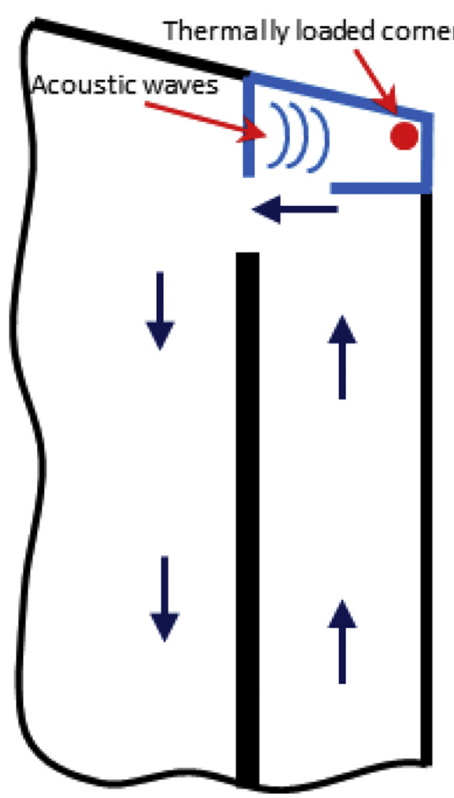


**Fig. 2.** Cooling system modification according to [8].