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STEAM-, GAS-TURBINE, AND COMBINED-CYCLE POWER INSTALLATIONS, AND THEIR AUXILIARY EQUIPMENT

The Influence of a Special Fillet between the Endwall and Airfoil at the Leading Edge on the Performance of the Turbine Nozzle Diaphragm

B. I. Mamaev[a], R. Saha[b], and J. Fridh[b]

[a] *OOO Siemens, Bol'shaya Tatarskaya ul. 9, Room 4.18, Moscow, 115184 Russia*
[b] *Royal Technological Institute, Stockholm, SE-10044 Sweden*

Abstract—It is shown from the results of experimental investigations carried out on a nozzle diaphragm's sector that an enlarged fillet at the vane leading edge does not have an essential effect on the flow and energy losses in the nozzle diaphragm.

Keywords: nozzle diaphragm, fillet, end losses, flow exit angle and vortex structure

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End losses may account for a considerable fraction in the total loss of energy in the turbine blade bucket if the blades have a relatively low height. Therefore, those who carry out gas dynamic investigations and design blade buckets pay much attention to development and investigation of methods for reducing end losses. Such methods involve the use of various structural elements preventing the formation of secondary currents in the bucket [1, 2]. The list of such elements includes, among other things, enlarged fillets in the junction between the airfoil and the endwall near the blade leading edge (Fig. 1). In recent years, the influence of such fillets on the gas dynamic characteristics of nozzle cascades has carefully been studied abroad of Russia (see [3–5] and others).

Experiments carried out on the linear cascades of nozzle profiles showed that the use of such fillets makes the channel vortex less intense and drive its core away from the wall. The influence of a fillet extends for more than 40% of vane height, and the loss of full pressure decreases by 7–14% [4, 5].

Investigations carried out on enlarged fillets of different geometries made it possible to work out recommendations on the most favorable shapes and sizes of these fillets. It has been determined [3, 4] that the fillet height over the leading edge l_0 must be equal to (1–2)δ, and its length along the lines of the profile's pressure and suction sides must be $S = (2–8)\delta$, where δ is the boundary layer thickness at the cascade inlet; it is most preferable to have a linear variation law of fillet height l along the line normal to the profile contour line (see Fig. 1).

It should be noted that, if the total energy loss coefficient ζ in the nozzle diaphragm is equal to, e.g., 0.08 at the reduced isetropic flow exit velocity $\lambda_{1t} = 0.9$, the above-mentioned reduction of losses due to the use of a fillet may result in improving the stage efficiency by up to 0.5%, which its a significant positive effect.

However, we cannot but point out that works [3–5] have serious drawbacks and come in contradiction with some other investigations. First of all, these and some other well-known studies that dealt with similar fillets were carried out on linear cascades. At the same time, it is well known that secondary currents occurring in a real nozzle diaphragm differ from the currents in a linear cascade [2].

Large-scale cascades were blown in [3–5] at low velocities $\lambda_{1t} < 0.2$. On the other hand, flow compressibility has an essential effect on the losses: e.g., according to [2], as λ_{1t} increases from 0.4 to 0.9, the end losses decrease by a factor of 2–3.

The main drawback of the well-known investigations is that their authors compared cascade versions with and without a fillet (the baseline). First, turbine buckets are usually made with fillets. Second, a usual fillet essentially alters the structure of secondary currents and reduces losses in the cascade (by analogy with a smooth junction between the airplane airfoil and fuselage) [6, 7]. The investigations were carried out with smoothed low-turbulent flow at the cascade inlet. At the same time, it is well known that flow prehistory (nonuniformity of the velocity field, degree of turbulence, etc.) has a strong effect on end losses [2, 5, 8].

The investigations reported in [4, 5] showed very clearly that the addition of a fillet causes the flow exit angle α_1 to increase; i.e., this measure weakens the cascade's ability to turn the flow. This is a negative effect, which leads to a decrease of the useful work done in the stage and can overpower the effect from reduction of losses. In this regard, the following main requirement for designing a cascade should be