18th International Conference
ENGINEERING MECHANICS 2012
Svratka, Czech Republic, May 14 – 17, 2012

pp. 1353–1361
Paper **#31**

FLOW CONDITIONS IN THE LAST STAGE DURING IDLING OPERATION AND LOW OUTPUT OF 1000MW TURBINE

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Abstract: *Measurement of temperatures at the tip of the last stage during startup and idle operation of the turbine with nominal output of 1000 MW is described. Monitoring of liquid phase coarse dispersion occurrence, the direction of drops movement and investigating whether the origin of the drops comes from the natural expansion of steam in the stage or from an additional cooling system is presented. The flow of the steam phase behind the last stage is determined.*

Keywords: ***Experimental measurement, steam turbine, low output***

1. Introduction

At low output levels of the turbine and during idling, the last stages are run in a ventilation mode. Due to the effect of centrifugal power, steam is transported to the tip of the rotor blade. Separation of the flow from the hub end wall occurs together with the suction of steam to the blading root section from the area of the output diffuser after the last stage. Backflow area is formed here. A part of the turbine stages performs the work, while another part partially or completely consumes it. An enclosed eddy area may be formed at the tip of the last stage during idling operation and very low turbine outputs. There is a certain risk of local overheating. The ventilation mode is accompanied by heat production. To prevent the overheating of last sections of low-pressure parts during operation of the turbine at a low output due to ventilation losses, additional cooling is installed on the internal side of the exhaust hood. Cooling water is injected into the area after the last stage. If the non-evaporated drops are caught by return flow, they may be sucked into the last stage and erode the blades near the root section radius. This phenomenon was first noticed on the trailing edges of the last stage of the 200 MW turbine Tajč & Bednář (2001). Therefore, there is an effort to place and direct the cooling system nozzles in such a way as to minimise the risk of damaging the blades. The objective of the performed experiments was to verify whether or not the last stage overheats at the tip of the blading, and whether the water droplets from the nozzles reach the rotor blades.

2. Arrangement of the experiment

Various types of probes may be placed in the area after the last stage during operation. The arrangement of measuring places is shown in fig. 1.

A comb ball probe is shown here for identification of liquid phase. The balls are covered with coating of suitable consistency. The droplets of water with the greatest erosion effect remove a part of the coating upon impact. A colour divide between the coated and the original surface is created. Using a simple jig, the impact direction of drops may then be determined.

A pair of thermocouples is used for measuring temperature. One thermocouple is placed in the well in the slot between the L-1 rotor blades and the last stage stator blades. The second well with the thermocouple is placed at the tip between the stator and the rotor of the last stage.

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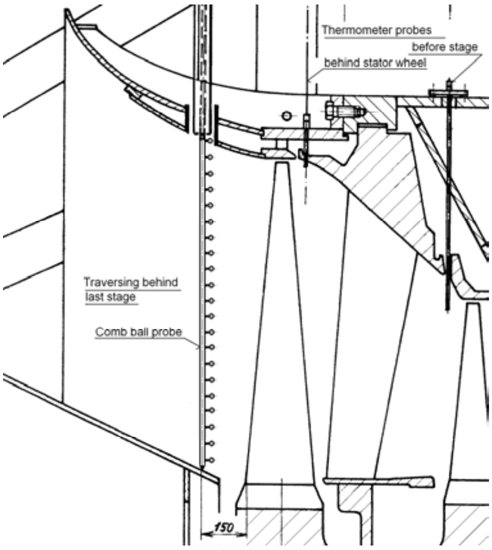

Fig. 1: Arrangement of measuring places in the last stage of the steam turbine

The movement of the steam phase may be verified using a multi-hole pneumatic probe behind the last stage. Suitable technical conditions were not created for measuring before the stage and between the diaphragm and rotor blading to determine velocity field. The flow character may only be estimated from the analysis of the velocity field behind the stage and then based on the findings from measuring similar output parameters of a 200 MW turbine with the last stage including a rotor blade 840 mm long (Tajč,1995; Šťastný & Tajč, 1977).

From the velocity before and behind the stage, a flow field model was arranged which is shown in fig. 2. Characteristic eddy structures are created at the tip and root section, whose existence may be assumed even in a stage with another rotor blade.

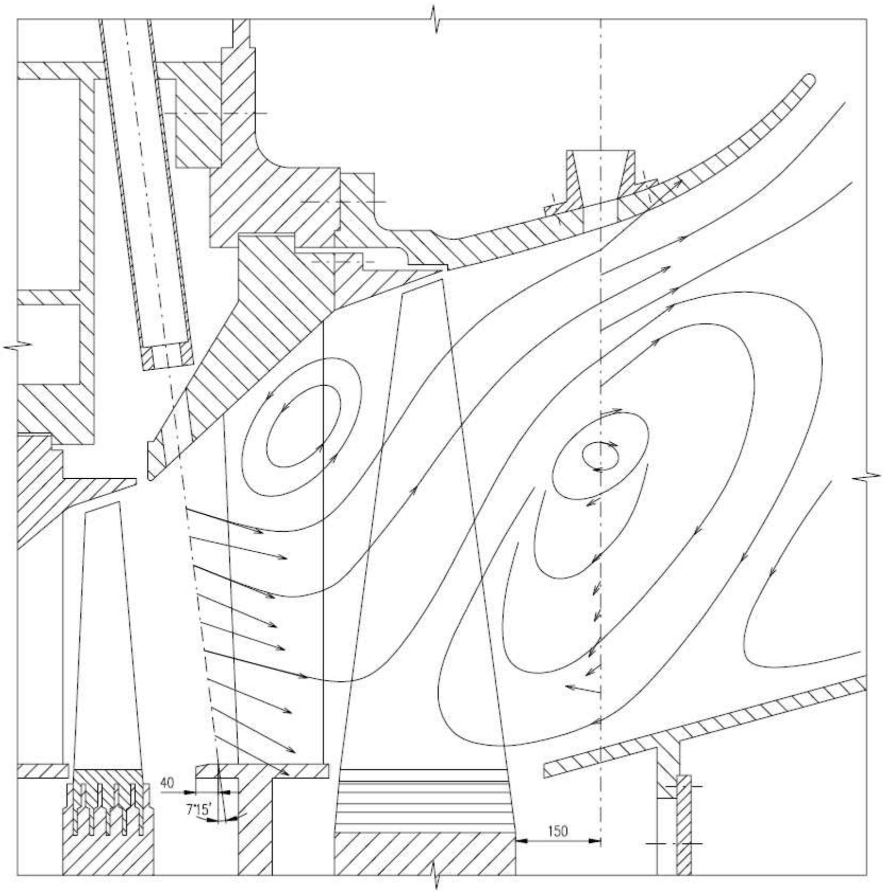

Fig. 2: Characteristic flow field in the last stage during idling operation

3. Measurement results

3.1. Measuring of temperature in the last stage

As the turbine output is lowered, the inlet pressure to the LP parts drops. Steam temperature after superheating changes in a substantial manner. During idling operation and low turbine output, superheated steam may occur in the last stage. Velocity is gradually increased during startup. Ventilation losses correspond to a third power of the speed. The temperature of any superheated stream in the last stage will increased with the velocity. In a wet steam, only the steam wetness and not the temperature would change. The temperature in the last stage at the tip during startup is shown in fig. 3 and fig. 4.

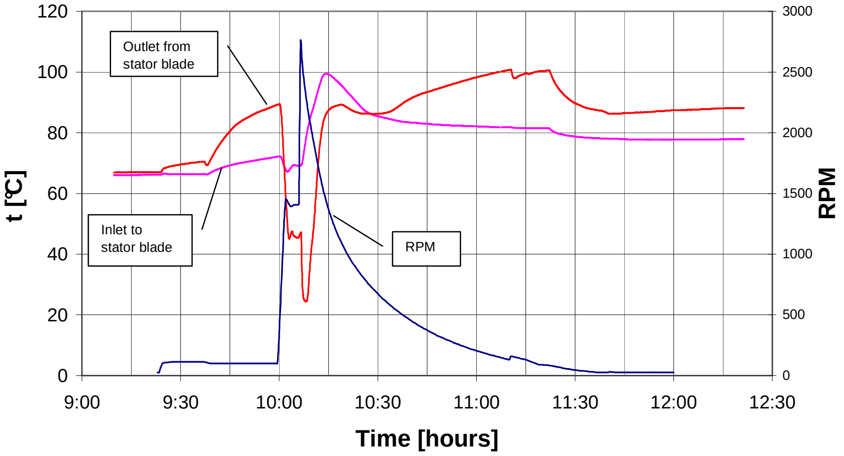

Fig. 3: Temperatures in last stage

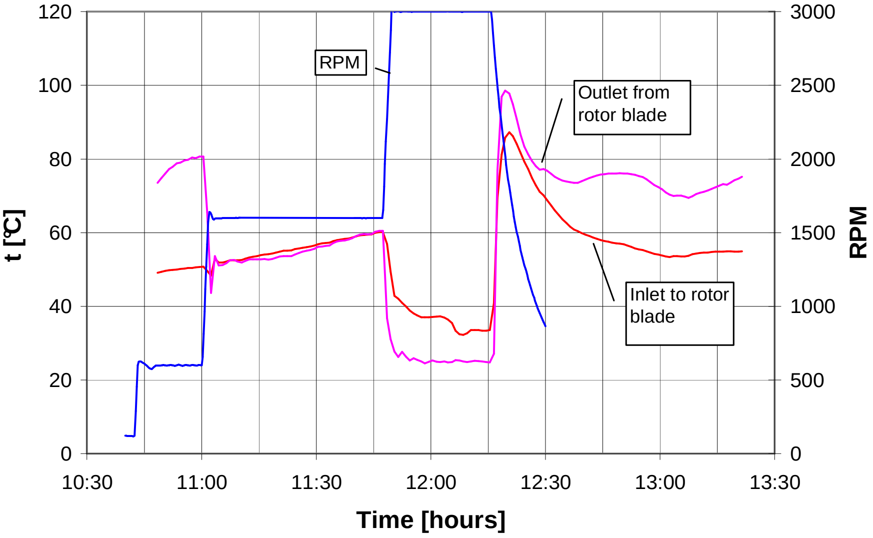

Fig. 4: Temperatures in last stage

Both cases show conditions during a step speed change - speed increase and shut down. If the turbine is on the turning gear, the temperature behind the stator blade is higher than behind the inlet to the stator blade. This is a ventilation loss effect. The temperature in both wells gradually grows. According to the condition of temperature values it is obvious that it is a mildly superheated steam. As the velocity increases so does the mass flow rate of the stage through the last stage. Steam parameters change when the temperature behind the diaphragm rapidly drops to the level of the saturation temperature at the given pressure. Superheated steam occurs again at the tip of the last stage during shutdown and a drop of speed when the temperature of the steam after the diaphragm cascade is higher than before it. If turbine operation passes from a warming-up speed (ca 1600/min) to full speed as confirmed by fig. 4 and fig. 5, a step change of temperatures occurs. The temperature behind the stator cascade is now smaller than the temperature at the inlet to the last stage. During long-term ventilation mode, temperatures in the last stage increase. The growth of temperature is also probably caused by the ventilation loss from the L-1 stage. Temperatures may be comparable here to the temperatures at the inlet to the LP part. Additional cooling of steam at the exhaust hood does not affect the temperatures at the inlet to the last stage.

The course of temperature and pressure values in the turbine during idling operation is shown in fig. 6. A substantial drop of pressure occurs at the control valve and the trapping flap. A part of the HP and LP stages participates in overcoming bearing loss and ventilation loss in other stages. The temperatures at the inlet and outlet from the diaphragm with turbine output at ca 200 MW, i.e. at 20% of loading are recorded in fig. 7. During this operation mode, temperatures are already stable. These are saturation temperatures for the given pressure in the stator cascade. The inlet temperature is higher because the pressure is higher as well. Similar conditions even apply for a higher turbine output. The pressure values recorded during turbine operation at 450 MW are shown in fig. 8. Higher temperatures before and behind the diaphragm document the changes in pressure distribution in the stage after transition to another output level.

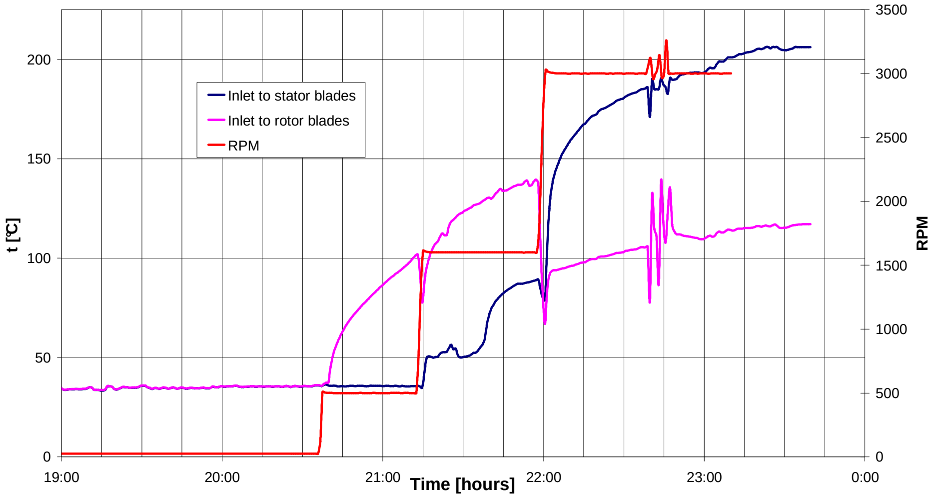

Fig. 5: Temperature in the last stage when starting up the turbine to speed

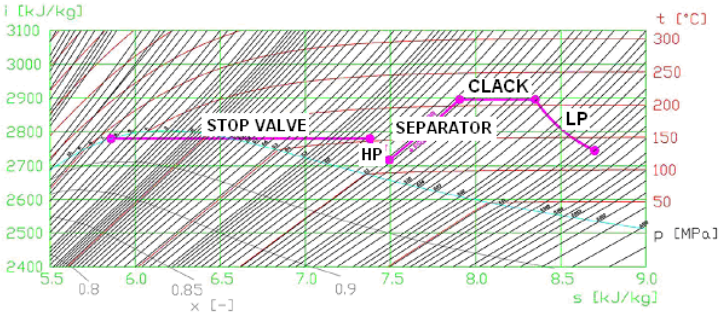

Fig. 6: Expansion of steam during idling operation

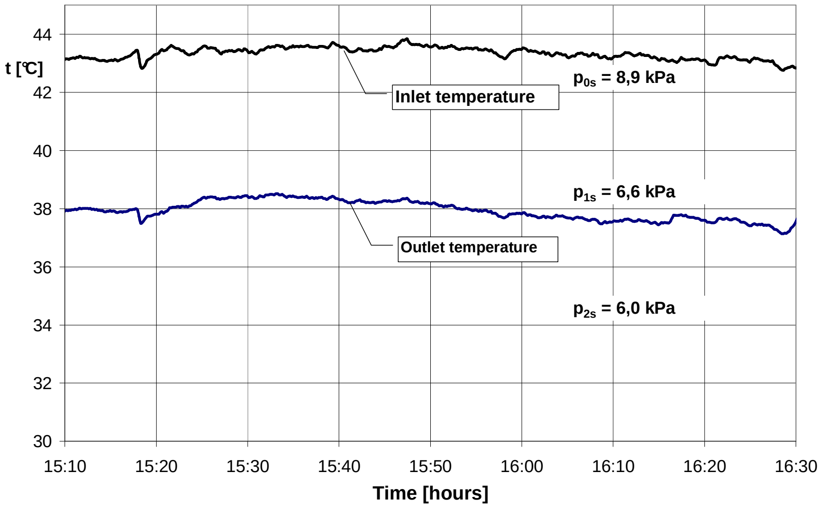

Fig. 7: Temperatures on the stator blade wih turbine output at 200MW

It is shown that there is no risk of a closed zone with substantial overheating in the last stage. Local heating of steam due to the existence of ventilation loss occurs only with limited rotor speed and during the long-term ventilation mode. However, it is not a long-term operational mode of the turbine. A transition in the last stage from wet steam to superheated steam, whose temperature depends on the time of ventilation operation, occurs at nominal speed. It is impossible to prove whether the additional cooling in the outlet part of the turbine affects the temperatures in the last stage. An experiment without additional turbine cooling and idling was not conducted. It may only be assumed that the artificially cooled steam may not reach the monitored place.

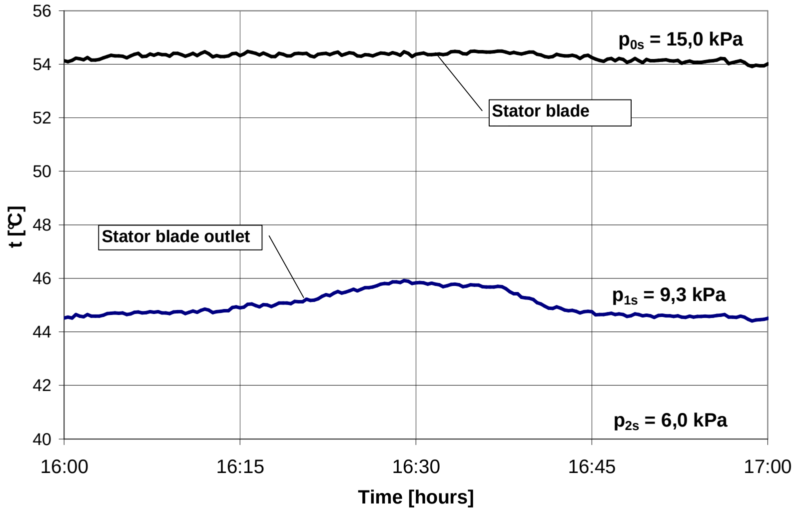

Fig. 8: Temperature on the stator blade with turbine output at 450 MW

The temperatures present on the external casing of LP body are shown in fig. 10. Fig. 9 shows the places where the temperature is measured. Three characteristic surfaces are distinguished. The internal and external front face and casing of the body are considered. The hottest place is on the cover of the seal at 0, where the temperature may reach as high as 100°C. It is affected by the heat of the steam flooding the seal. The temperature evenly decreases along the radial line towards the external casing and levels off at the saturation temperature for the given temperature at the exhaust hood. An even distribution of temperature values was apparent in all operational modes including idling. A lower temperature on the external casing is only found in the securing diaphragm areas. During idling operation, a lower temperature is present on the surface of the external body than that which would correspond to the saturation temperature. It means that cooler water from the cooling system reaches the internal surface of the external casing.

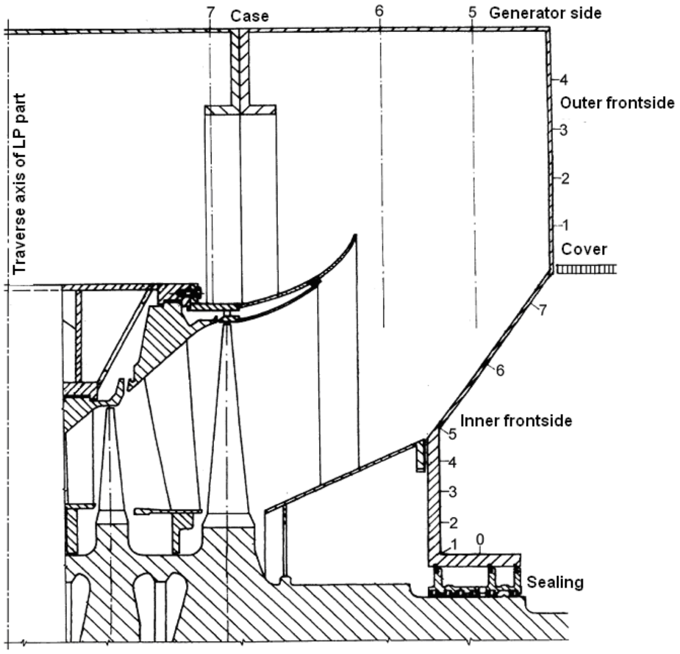

Fig. 9: Temperature measuring places

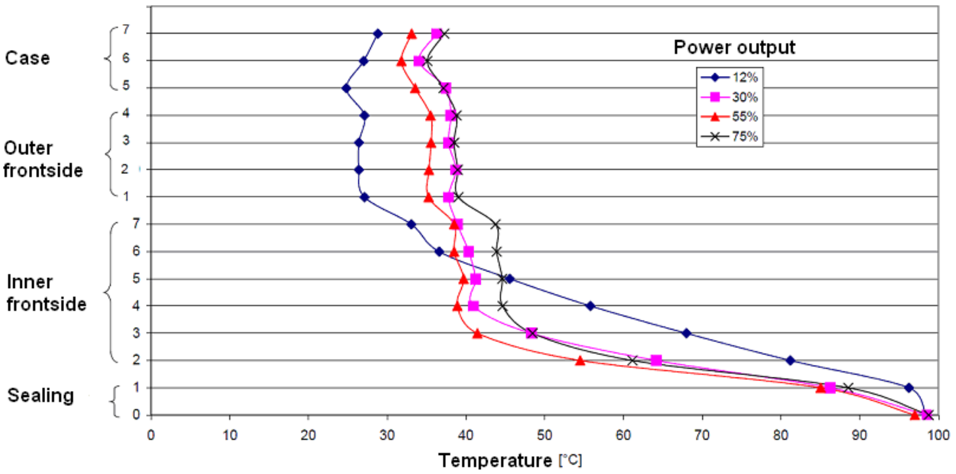

Fig. 10: Temperature on external casing of LP part

3.2. Identification of liquid phase

The occurrence and movement direction of coarse dispersion liquid phase using an erosion probe is monitored behind the last stage on the right and left side of the turbine. The erosion effect of drops differs according to the distance from the blading root section. The highest effect tends to occur at the tip of the rotor blade. As the experiment was to verify the origin of droplets at the root of the blading, the exposition time was governed by the need to capture the effect of droplets near the hub radius. It is always necessary to take various differences in 3D flow along the perimeter of a stage into account. This is the main reason for measuring and recording of data on the right and left side of the turbine.

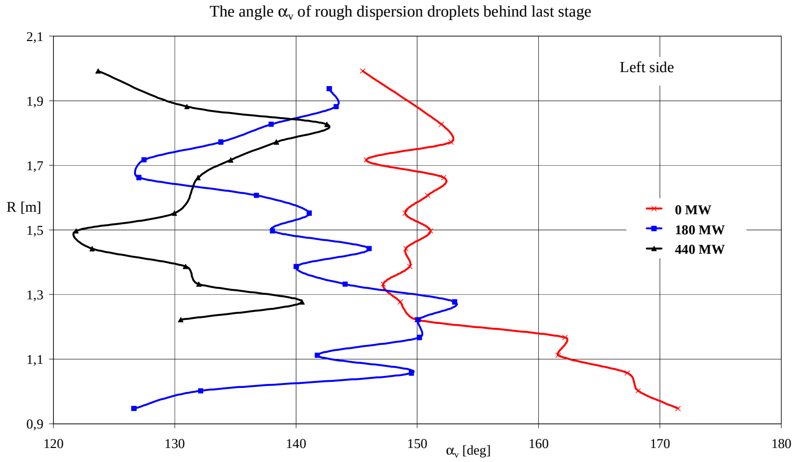

Fig. 11: Movement of droplets behind last stage

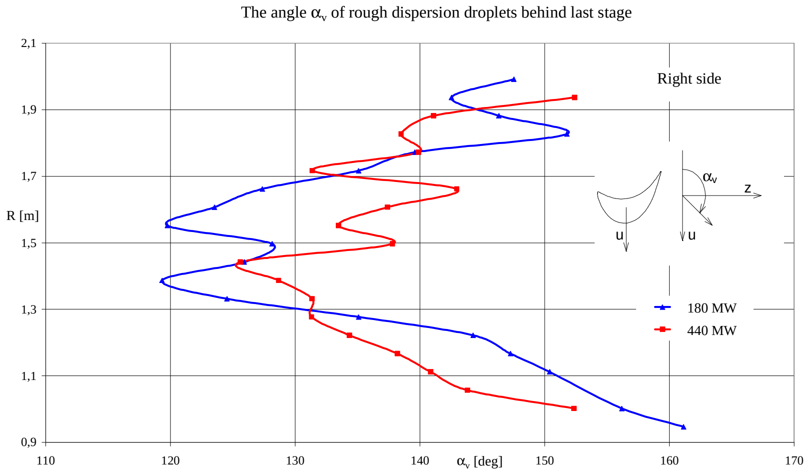

Fig. 12: Movement of droplets behind last stage

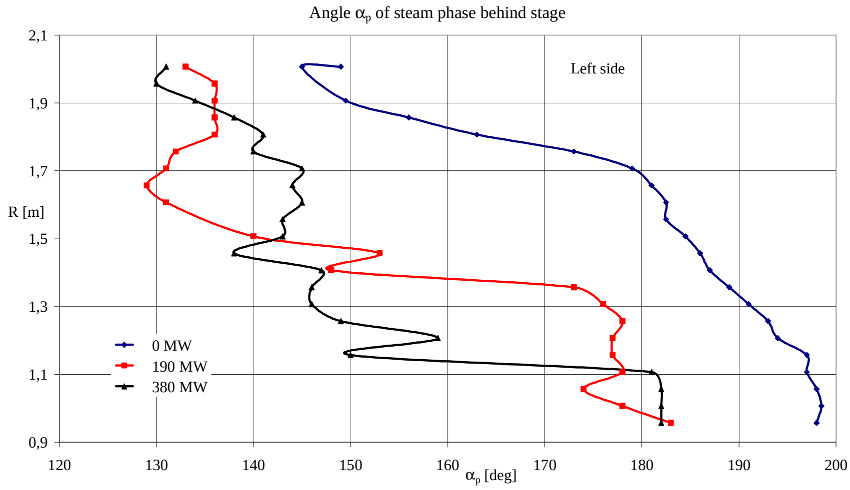

Fig. 13: Direction of movement of steam

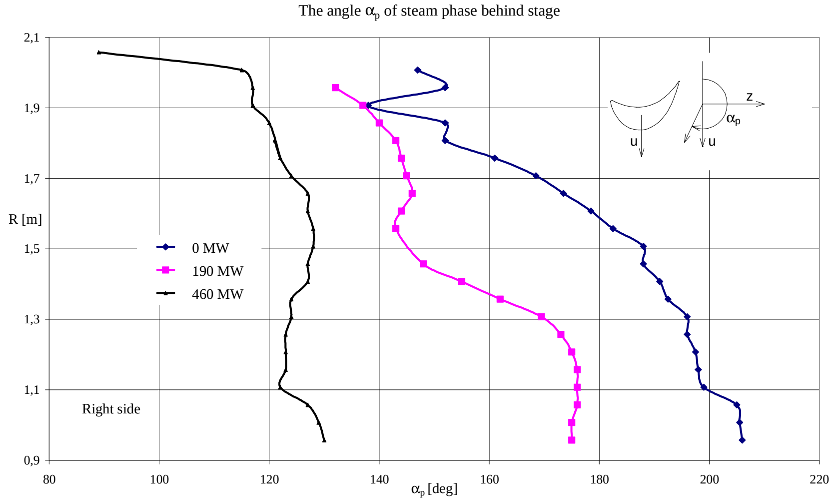

Fig. 14: Direction of movement of steam

The water drops are not monodisperse. Their size differs and the direction of movement is more or less affected by the movement of the steam phase. To which the erosion displayed on the surface of the balls of the erosion probe corresponds. An estimate of the direction of droplets movement is therefore always subject to the subjective effect of the experimenter. Therefore information about the direction of droplets movement needs to be taken for guidance only. However, it is certainly possible to see whether the droplets are moving to the blades or away from them.

Droplets movement in the circumferential direction is shown in fig. 11 and fig. 12. It was revealed that during idling operation (output 0 MW) droplets occur only on the left side of the low pressure part. Angle α_v is a projection angle of the vector of droplets speed in the plane defined by circumferential and axial direction. If $\alpha_v > 180°$, then the droplets move towards the rotor blade. It shows that this instance does not occur even during idling operation. At the root, the angle α_v is greater than in the central part of the stage. The movement of the steam phase in the area behind the stage is shown in fig. 13 and fig. 14. The backflow of steam was established during idling operation and low output. The direction of droplets movement did not correspond to the direction of flow of the steam phase. Water droplets of coarse dispersion are not carried by steam at the root section. Therefore, these are not droplets from the additional cooling system but droplets from the flow-through part of the turbine. Provided droplets are moving mainly due to inertia and are removed from the trailing edges of blades and the rotor disc, it is possible to determine the original place of drops using directional angles.

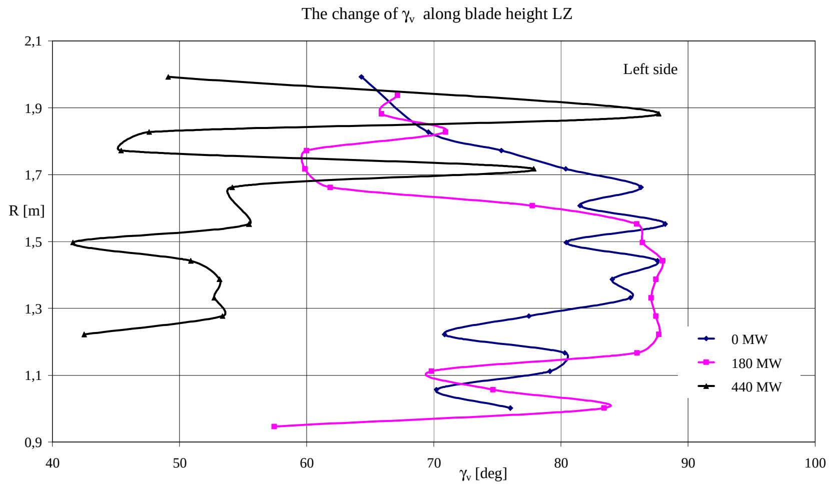

Fig. 15: Direction of droplets movement

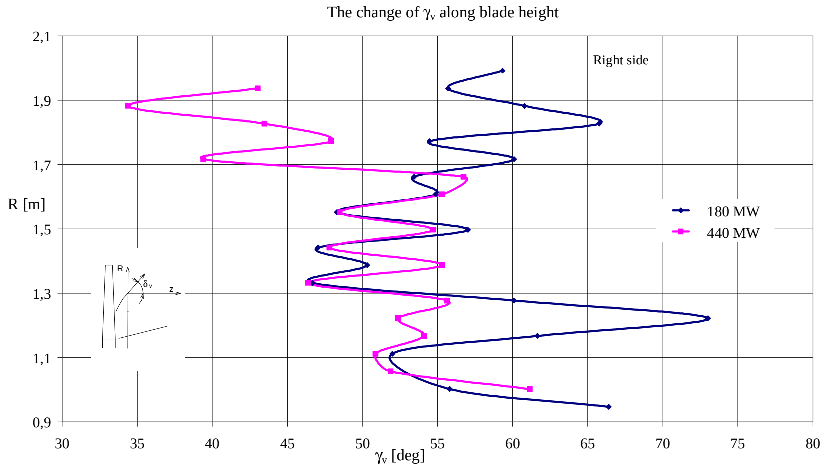

Fig. 16: Direction of droplets movement

The angle of the droplets movement γ_v perpendicular to the rotor for the right and left side is shown in fig. 15 and fig. 16. The measured angles are rather unbalanced. It applies in particular to the left side of the turbine. There is a possibility that there are places on the blade from which more water is removed than from others. It is also shown on the quality of the eroded coating on the balls of a comb probe. The final idea of the radius on trailing edges R_{oh} from which water droplets are dragged is stated in fig. 17 and fig. 18. The droplets, which are caught on the erosion probe placed 150 mm behind the rotor blade near the root section, come from the rotor disc. The origin of droplets is usually from the wider section of the blade. It depends on their size and the degree of impact of steam flow on the direction of droplets movement.

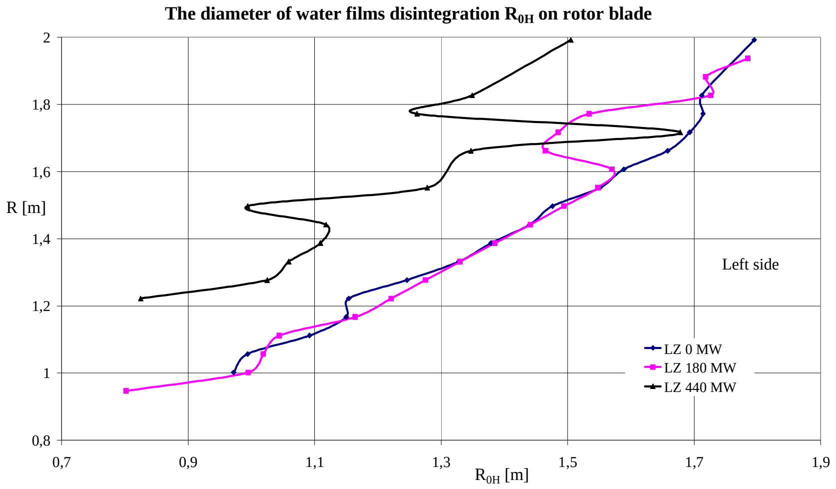

Fig. 17: Places of origin of droplets

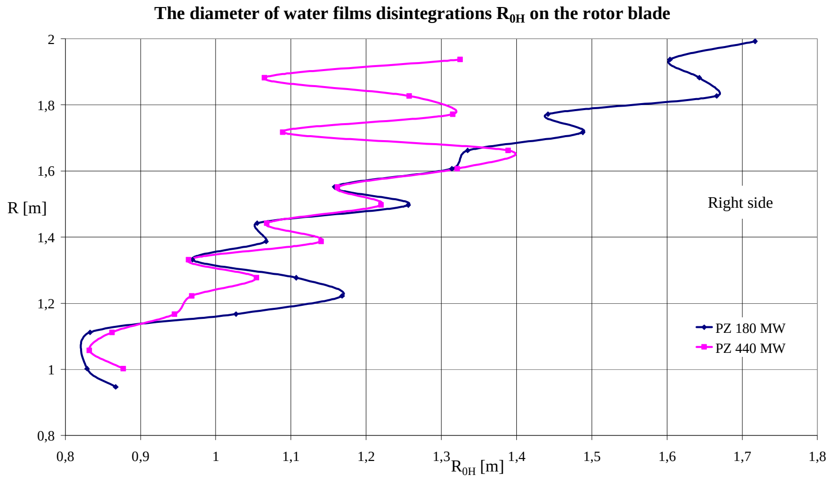

Fig. 18: Places of origin of droplets

4. Conclusions

Areas with backflow are formed in the last stage during idling and under decreased turbine output. A closed eddy zone is formed near the tip at the stator blades.

Due to ventilation losses, heat is produced in the blading part and the steam is heated. A part of the stages work on balancing the bearing losses and covering the ventilation losses during idling operation.

Operation temperatures in the last stage may be comparable to temperatures at the inlet to the LP part due to ventilation losses during turbine idling.

Flow conditions are modified at the tip of the last stage during a gradual growth of speed. A lower temperature may be seen in the inlet to the diaphragm than at the outlet.

The cooling system of the exhaust hood probably does not affect the flow and temperatures in the last stage.

Water droplets from the cooling system do not reach as far as the root of the rotor blade in the last stage.

Coarse dispersion droplets after the last stage move in the direction away from the blades in all operation modes. This also applies to the conditions when return flow occurs at the root section in the last stage. The origin of the droplets comes from the disc of the stage and from trailing edges of rotor blades.

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