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OCCURRENCE OF BIG DROPLETS IN THE VICINITY OF THE LAST STAGE OF A 210MW STEAM TURBINE

V.Uruba, P.Jonáš, O.Mazur, V.Řehák*

Summary

The method of detection of "big" water droplets in the wet steam flow based on hot-wire anemometry is used for analysis of the flow behind the last stage of the 210 MW steam turbine in two operational regimes. Lengths of associated events and period of theirs appearance have been evaluated, statistically proceeded and presented.

Introduction

To gain insight into complex physical processes going on in a steam turbine, better understanding the phenomena accompanying variability of parameters in the flow-field is necessary. Due to the complex nature of the velocity, temperature and pressure unsteady fields (steady, harmonic and random components) a thermo-anemometer is well suitable for experimental investigation of their dynamics. The authors worked up the procedures of the hot wire performance in the water steam flow [1], [2], [3], [4] and they have made so far several attempts of the unsteady flow characteristics measurement in the vicinity of the low-pressure stage of a full-scale water steam turbine.

The wet steam in operational conditions near the last low pressure stage of a steam turbine could be considered as a continuum containing a limited number of a large water droplets. The notion "big" means, that the size of droplets is of about two orders of magnitude greater then is the typical size of the droplets in the steam flow. Those "big" droplets could be detected in the relatively smooth anemometric signal corresponding to a continuum media, as abrupt voltage peaks reaching oftentimes limits of the anemometric apparatus.

The presented results have been obtained during measurements on the 210 MW steam turbine in power station Prunéřov II in 2003. Analyzed data has been acquired behind the last low-pressure stage at two operational regimes. The first was a nominal regime 210 MW, the second one with power reduced down to 140 MW.

Measuring technique and detection method

The wet steam in operational conditions near the last low pressure stage of a steam turbine could be characterized by the static pressure and temperature 6780 Pa and 312 K

* Ing.Václav Uruba, CSc, RNDr.Pavel Jonáš, DrSc, Oton Mazur, prom.fyz,. Ing.Vratislav Řehák, Institute of Thermomechanics, AS CR, E-mail: uruba@it.cas.cz

respectively and the mean flow velocity of order 10^2 m/s (after Šťastný [7]). The most probable diameter of droplets is 10^{-7} m (after Petr and Kolovratník [8], [9]) and the estimate of the Kolmogorov length scale (size of the smallest turbulent disturbances) is of the order 10^{-3} m. From data given above we can estimate that extremely large amount of droplets (of order 10^9) occurs even the smallest turbulent disturbances-fluid particles. The time scale referring to the action of small droplets is of order from 10^{-9} up to 10^{-8} seconds, corresponding frequency of order 100 MHz is far from the frequency range of turbulence.

The constant temperature anemometer DISA 55M with a single slanted hot-wire probe DANTEC 55P01 rotating around its axis was used for the measurements in steam turbines. The probe is equipped by a gold-plated tungsten wire with diameter of 5 μm and length of the sensor 1.2 mm. For the purpose of the droplets detection the wire was oriented perpendicularly to the mean flow and high temperature heating to approximately 530 K.

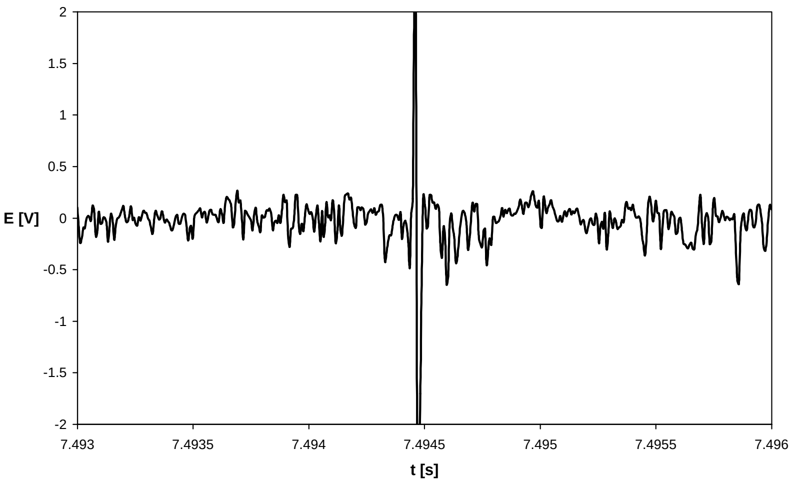

Fig.1 – Signal corresponding to a „big“ droplet appearance

Those “big” droplets were detected as abrupt and high voltage peaks to positive values – see Figure 1. A “big” droplet appeared at the time 7.4945 and it is characterized by high positive peak followed by negative peak. Appearance of the secondary negative peak depends on the conditions, sometimes it is quite weak or even missing. The first positive peak represents itself increasing cooling of the wire connected with higher thermal capacity of the liquid phase, while the second negative peak is consequence of the overexcited anemometers amplifier inertia, which needs a certain relaxation time to restore regular operation.

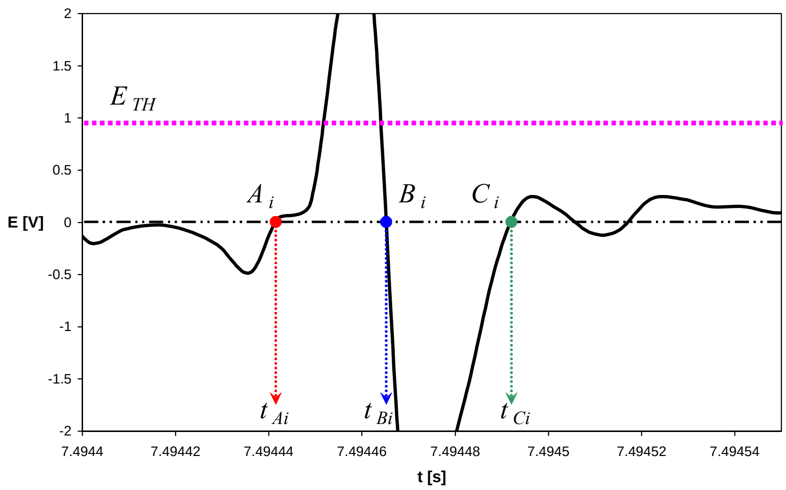

Fig.2 – Detection of a “big” droplet

As the peak corresponding to a droplet is higher then “normal” signal fluctuation, certain threshold voltage value has been chosen as a droplet detector. Choice of the threshold level is a crucial point of the detection method. Best results have been obtained applying the idea, that the threshold level is given by the signal mean value plus

N-times signal standard deviation. The signal statistics are to be calculated removing the detected peaks, so iteration procedure should take place. The *N* value of 5 seems to be the most suitable. In Figure 2, the zoomed signal from Figure 1 is shown. The peak is obviously higher then the threshold voltage E_{TH}, three crossing points with the mean value level A_i, B_i, C_i are detected and corresponding times t_{Ai}, t_{Bi} and t_{Ci} are evaluated respectively.

The signal statistics are calculated dropping the signal between the points A_i and C_i for all events. The event length could be defined as t_{Bi} - t_{Ai}, while the period of appearance of subsequent events could be defined as t_{Ai+1} - t_{Ai},

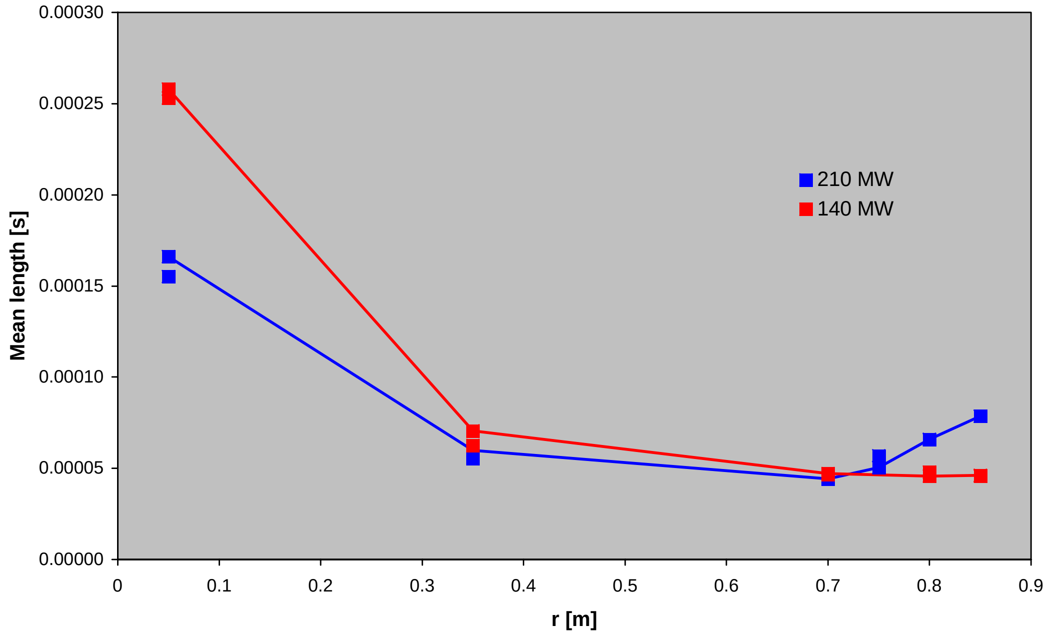

Fig.3 – Mean length of events

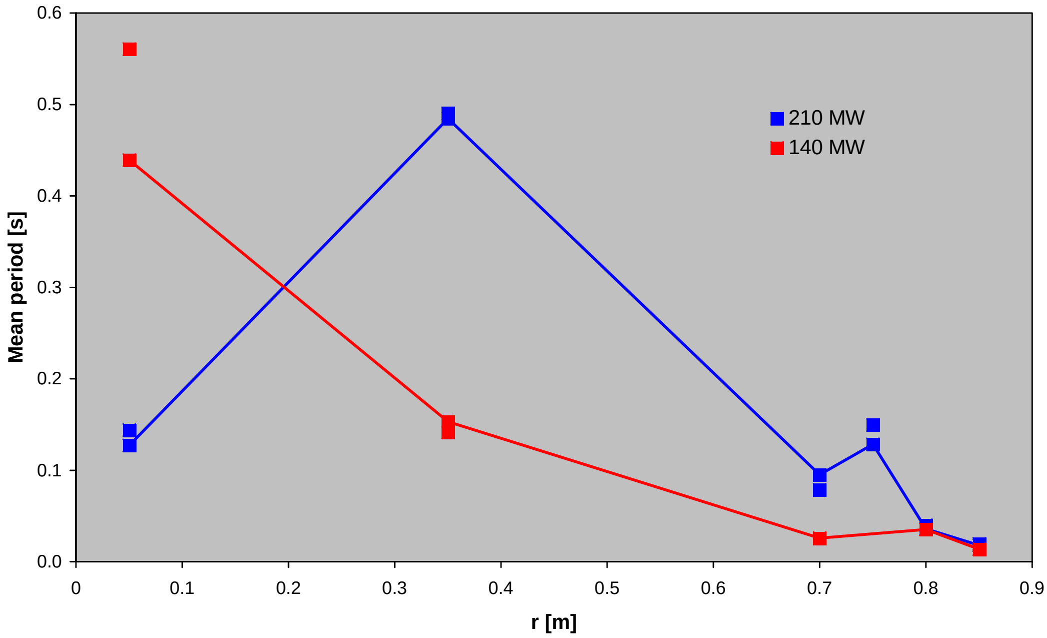

Fig.4 – Mean period of event appearance

Results

The experiments have been carried out in the power station Prunéřov II on a 210MW ŠKODA steam turbine. Radial profiles 0.15 m downstream the last low-pressure stage were measured using the hot-wire probe. The radial coordinate *r* [m] is measured from the root to the tip of blade. Two operational regimes corresponding to full (210MW) and partial (140MW) turbine output power were investigated.

In Figures 3 and 4 profiles of mean length of "big" droplet detection events and mean period of theirs appearance are shown respectively.

Near the blades root (r = 0.05 m) relatively large-length events appear in moderate frequency. Both events length and appearance period is considerably greater in the case of low turbine power, while full power gives smaller events length, but much higher frequency of the droplets occurrence.

In the blade central part (r = 0.35 m) the mean events length is for both regimes near 50 μs, while the events occur 5-times more frequently in low turbine power case than in its full power operational mode.

Near the blade tip (r = 0.7 – 0.85 m) the mean events length is still nearly the same as for the central blade part, however it is slightly smaller for the turbine low power mode. But still frequency of appearance of the events is much higher for the low power mode.

Globally could be said, that the mean event length varies around the typical value of 50 μs with exception of region near the blade root, where it reaches values 3 or 5 times higher, depending on the turbine power regime. The events appearance period basically falls down moving from the blade root to its tip and it is considerable lower for the case of low power, except the point near the root, where full power shows 4-5 times lower value then the low power.

Histograms of examined quantities were also evaluated – see Figures 5, 6, a, b. The abscissa showing probability density function value is normalised to give the integral equal to 1. Generally, we could recognize most of histograms complying the log-normal distribution with relatively high and sharp peak. However, a few relatively broad distributions could be recognized. This is the case of the position near the blades root (r = 0.05 m) for lower power mode and the central position (r = 0.35 m) for the full power mode. This result indicates presence of irregularity in steam behaviour in those regions.

Conclusion

Analysis of the CTA anemometer output voltage records could provide information a wide range of kinds concerning the wet steam flow. The output signal is the result of superposition of the effect of quasi continuum flow disturbances and of the strong disturbances caused by impact of "big" water droplets on the hot-wire. In the presented study effective applicability of the method for the "big" droplets detection has been shown. The results are of a special importance, while essentially there is a lack of an effective method for detection "big" droplets in a wet-steam flow. On the other hand, actually we have no possibility to prove obtained results using an independent method.

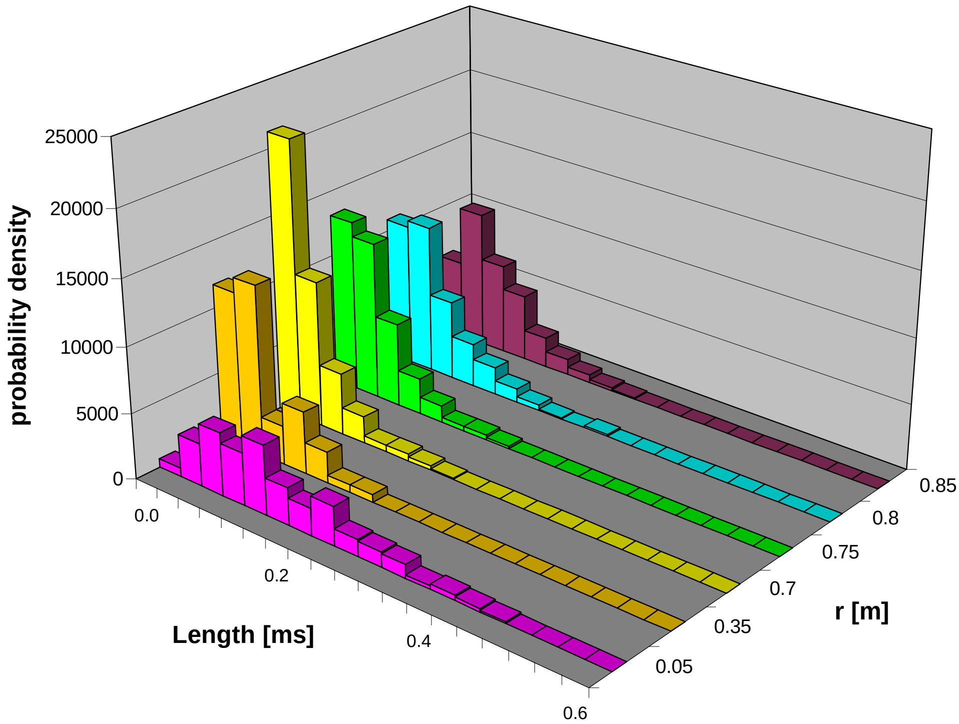

Fig.5a – Histogram of the events length, 210MW

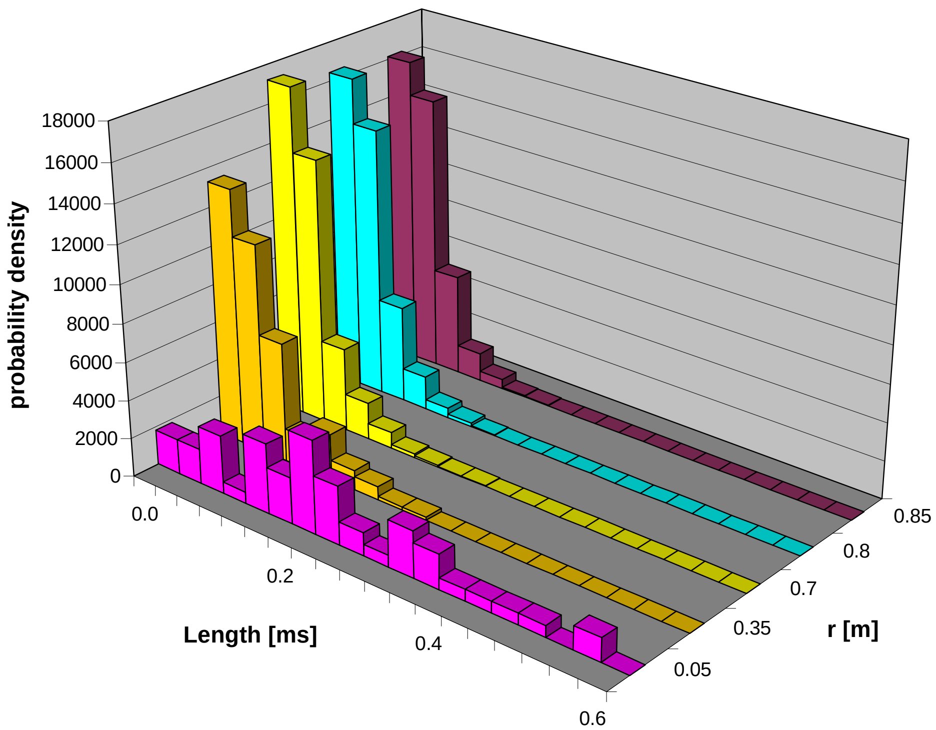

Fig.5b – Histogram of the events length, 140MW

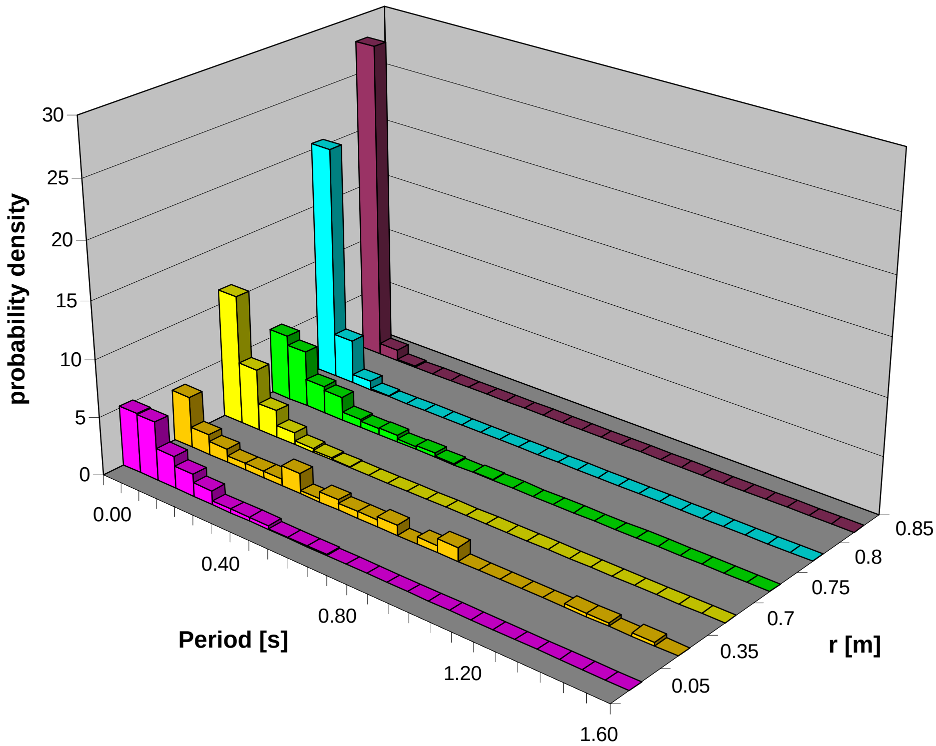

Fig.6a – Histogram of the events period, 210MW

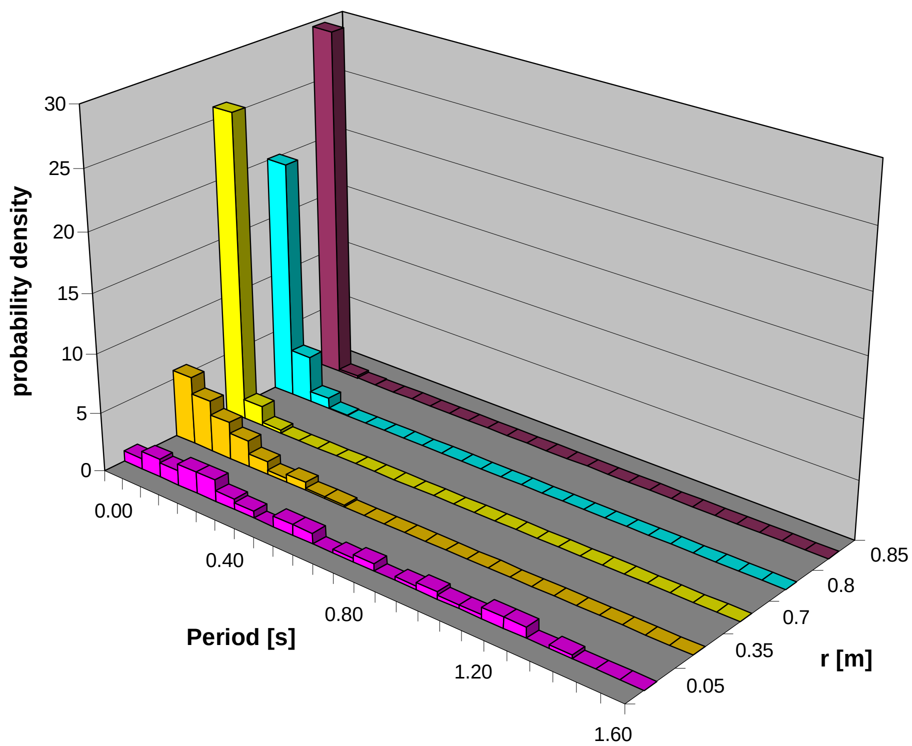

Fig.6b – Histogram of the events period, 140MW

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