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Experimental investigation of the flow near the ram element in the brush turbine

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Abstract. The paper focuses on the investigating of the parameters of the fluid flow around the brush turbine ram element. The flow field was evaluated qualitatively by observing changes in density using a Schlieren method. It was also evaluated the influence of the element geometry on the total aerodynamic force of the element. The aerodynamic force was measured directly using a special aerodynamic balance. The aim of the project was to find the simplest element geometry with a maximum force effect and achieve an increase in overall efficiency and reduce the manufacturing costs.

1 Introduction

The steam turbines for small performances are generally designed as a single-stage radial or axial machines, because the mass flow rate of steam is not enough for effective use of multi-stage turbines. For these applications the small single-stage turbine, so called steam rotating reductions, are more suitable. These turbines were previously used in large power plants and heating plants for the use of steam power, which would otherwise be wasted by pressure reducing. Today, these machines are increasingly being used as the primary source for electricity generation. Their main advantages are simplicity of design and the associated low costs and ability to handle large thermal gradient in a single step. This article focuses on an innovative way of solving these rotating reductions. Here the kinetic energy of the steam exiting the nozzle is used. Steam is directed to the ram air turbine rotor elements, where there is a transfer of energy. The turbine is designed to 3000 ot / min, thus eliminate the need for a gearbox. It is needed to ensure that each ram element has a maximum drag to achieve a high efficiency of the turbine. This paper describes the experimental evaluation of the aerodynamic drag force depending on the geometrical shape of a ram element. It describes the experimental device and measurement results obtained to date.

2 Theoretical background

Water vapour is tangentially delivered on the turbine disc and directed to the ram elements (Figure 1). These ram elements may be placed both radially and axially in the rotor disc [1]. The turbine unit can operate in either subsonic or supersonic regime. The mode depends on the ratio of the pressures upstream and downstream of the Laval nozzle. If the ratio of pressures p1 / p2 is greater than Beta critical and if the nozzle is suitably designed, the ascent rate can to achieve supersonic speed [2, 3]. The fluid of these parameters subsequently encounters the ram element and creates a shock wave in front of it (Figure 2).

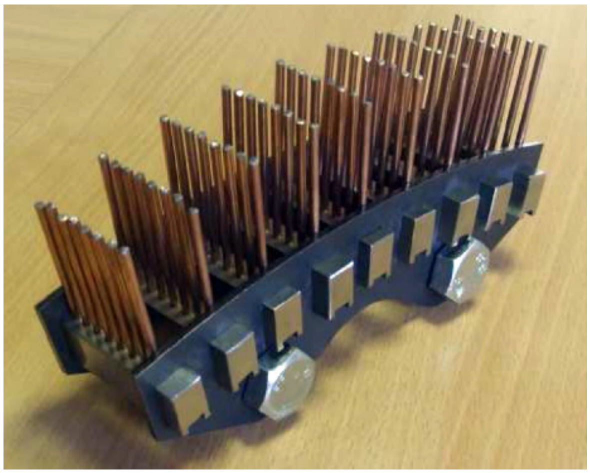

Figure 1. Real turbine ram element.

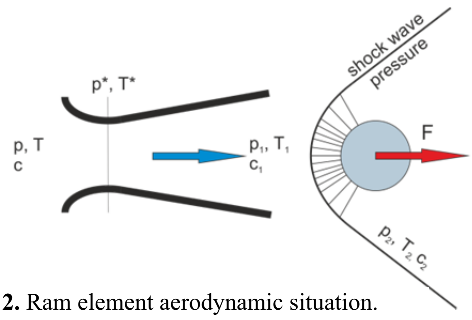

Figure 2. Ram element aerodynamic situation.

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The shock wave pressure effects on the element and rotates the turbine. The shock wave also protects the ram elements from the erosive effect of the water droplets. The machine is thus able to a long-term operation in wet steam. In the case of flow around a multiple element located in close the shock wave extends across the whole segment and the force effect is considerably amplified (Figure 3). Experiments have shown that about 80% of the energy is absorbed by the first line of the ram elements.

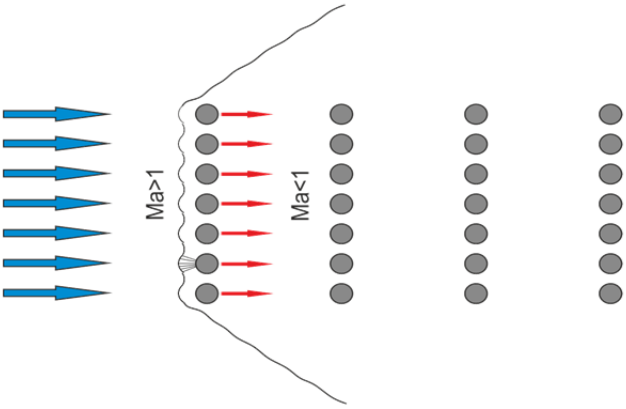

Figure 3. Multilayer ram element aerodynamic situation.

3 Experimental setup

The high-speed track with adjustable Laval nozzle (Figure 4) was designed to measure the aerodynamic force effects. The track is powered by compressed air coming from a tank with a volume of 13 m^3. A screw compressor with a power of 90 kW is use to pressurize the tank.

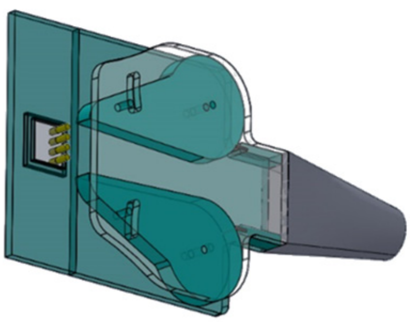

Figure 4. Experimental setup with a Laval nozzle.

Figure 5. The floating element with a tensometric balance.

The Laval nozzle was during the whole experiment adjusted for the maximum pressure 1.7 bar before the nozzle. So the output flow reached the Mach number Ma = 1.5. The pressure and the temperature in the front of the nozzle and the pressure and temperature at the critical point of the nozzle were recorded during the measurement.

The universal floating element (Figure 5) was placed on a strain gauge transducer. The strain sensor has a measurement range about 15 kg and was calibrated using a precision digital force transducer. The ram elements were placed on the floating element according to the required geometry. This way the aerodynamic force on the ram element caused by the flowing liquid was measured. Air was used for all measurements as a flow liquid. The force acting on the empty floating element without the ram elements were subtracted from the measured force effects. Tested ram elements have a diameter of 4 mm and the length of 20 mm. The elements are made of steel.

4 Results

The distribution of the pressure field around the ram

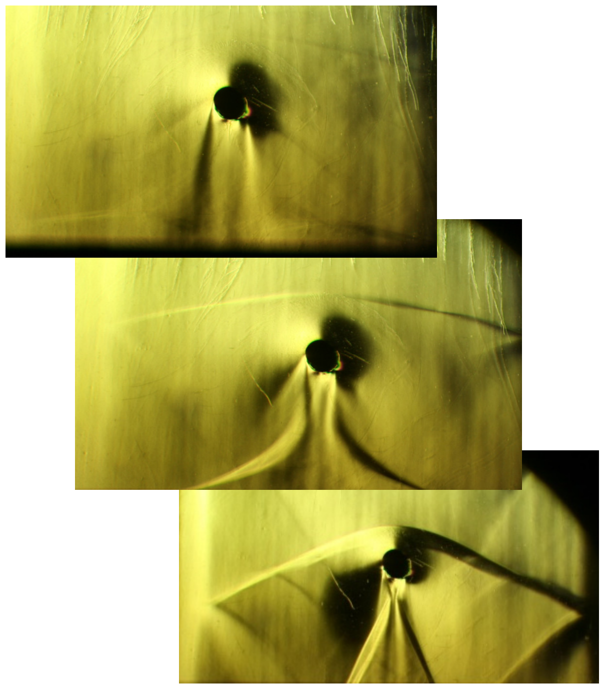

Figure 6. Shockwaves around the ram element. Pictures obtained for Ma = 1, Ma = 1.2 and Ma = 1.5. Schlieren method.

element was first observed using a Schlieren device [4]. It is possible to observe the formation of shock waves around the ram element in the taken photos (Figure 6).

Several variations of geometrical arrangement of the ram elements were measured. First, the empty floating element was measured for each variant, then the ram elements were placed and the measurement was repeated (Figure 7). The resulting force is the difference between the force measured with ram elements and force on the empty floating element. The pressure in the front of the Laval nozzle was gradually increased from 0 Pa to cca

160 kPa for each measurement. One measurement took about 2 minutes.

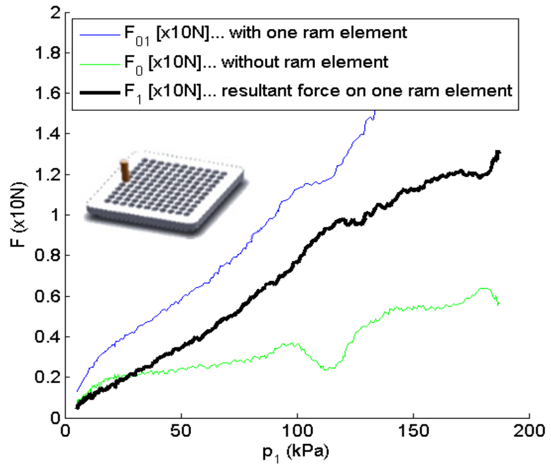

Figure 7. The results of one ram element force testing.

The different variants of ram elements distribution were tested subsequently. These variants are described in the following table (Figure 8).

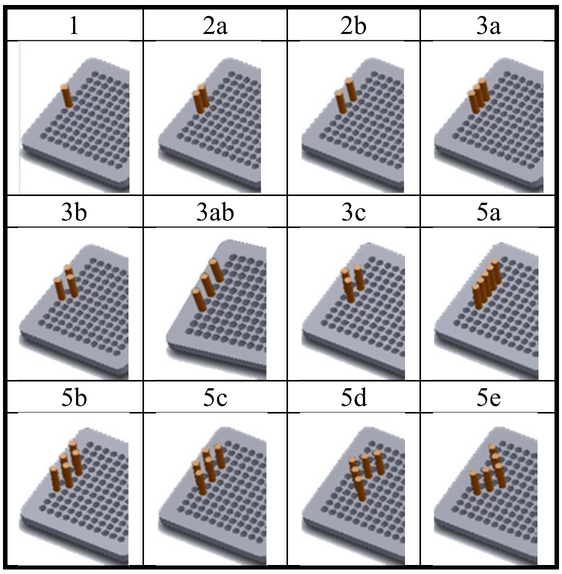

Figure 8. Ram element tested variants.

The aim of the experiment was to find the geometrical arrangement of the ram elements that will generate the maximum resistive force. Only the variants with the same frontal area can be compared. Practically this is an area formed by the outer pins and by their height. The variants with the same number of ram elements were therefore comparable. The comparison of resulted aerodynamic force effects on individual variants is shown in the Figure 9.

The variations with the same number of ram elements are shown for a more detailed comparison. The arrangement with 3 ram elements are shown in the Figure 10.

The figure shows that the greatest force effect exhibit the ram elements located in one row. By contrast, the smallest aerodynamic drag shows a variant **3c**. It is evident that the change in the distance between the ram elements does not play a significant role (variants **3a** and **3ab**).

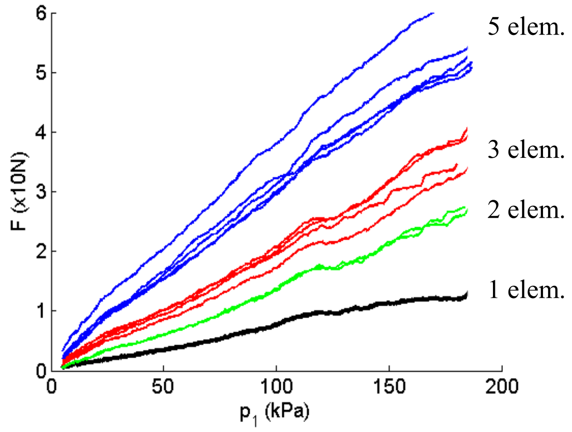

Figure 9. The resultant force on different ram element variations. Lines: red – 1 element, black – 2 elements, blue – 3 elements, green – 5 elements.

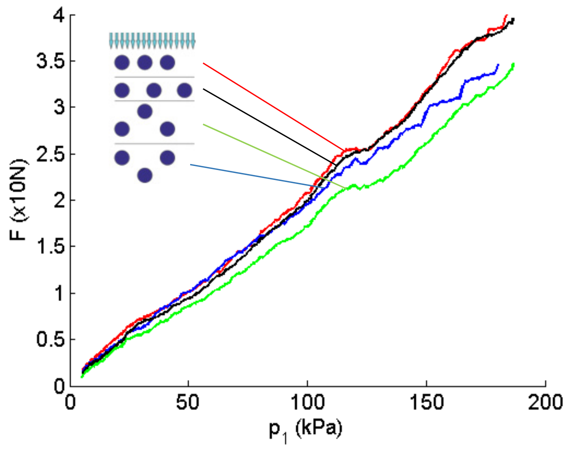

Figure 10. The aerodynamic force on 3 ram elements with a different geometrical arrangement.

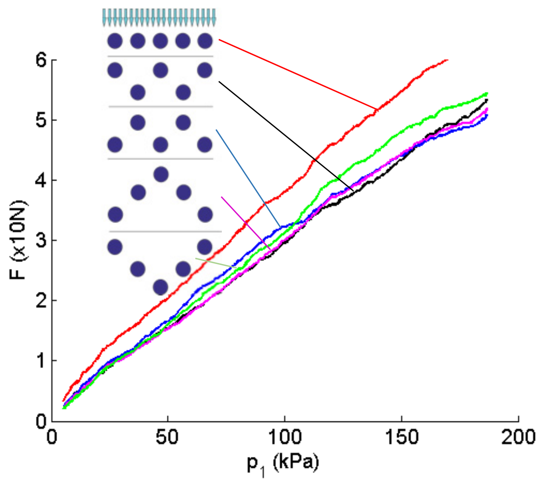

Figure 11. The aerodynamic force on 5 ram elements with a different geometrical arrangement.

The comparison of the arrangement with 5 ram elements is shown in the Figure 11.

Similarly as in the case with three elements, there is also observed that the greatest drag show ram elements located in one row. Other arrangements do not show significant differences.

The effects of the shape of the element was tested in the next. It is shown the comparison of the aerodynamic force on one ram element with a circular and square cross-section in the Figure 12.

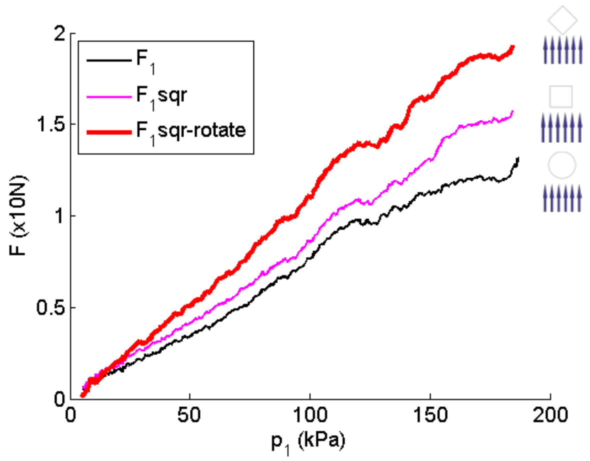

Figure 12. A comparison of the shape of the element on the aerodynamic resistance.

The experiments have confirmed a significant impact of the shape of the ram element on its aerodynamic properties. In the case of an element with a square cross-section its maximal aerodynamic drag is achieved in the case of rotation of 45° diagonally to the flow.

Conclusion

The high-speed track to the measurement of drag characteristics of the ram elements was made. Several geometrical arrangements of pins in ram element were measured. The best performance of ram element was chosen by comparing the values of drag force at geometries with the same frontal area. Experiments showed that the largest value of drag exhibit the ram elements arranged in one row. The significant impact of the ram element shape on the aerodynamic drag was confirmed. We also confirmed significant impact of the shape of the ram element on its aerodynamic resistance. It was also confirmed that a rotation of a square ram element diagonally to the stream can significantly increase the aerodynamic drag.

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