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НАБЛЮДЕНИЯ ВЪРХУ РАБОТАТА НА ХИДРОСТАТИЧНА НАПОРНА МАШИНА

OBSERVATIONS ON THE OPERATION OF THE HYDROSTATIC PRESSURE MACHINE

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Резюме: *Целта на изследователския проект HYLOW, финансиран по 7-ма Рамкова програма на Европейската комисия (завършен в края на февруари 2012) е разработване на нови хидроенергийни конвертори за много ниски напори в диапазон от 0,5 m до 2,5 m. Необходимостта от разработването на такъв тип хидроенергийни конвертори е обоснована от добре известният факт, че прилагането на конвенционалните водни турбини, в този диапазон на ниски напори е икономически неефективно. Един от разработените и изследвани, в рамките на проекта, хидроенергийни конвертори е така наречената Хидростатична напорна машина (ХНМ). За нуждите на изследователската разработка и постигане на формулираните цели, на съществуващ праг на река Искър беше изградена експериментална малка водноелектрическа централа, оборудвана с прототип на Хидростатичната напорна машина в реален мащаб.*

В настоящата статия са представени някои наблюдения върху работата на ХНМ по време на експериментите, проведени при различни реални условия на работа. Описани са физични явления, свързани с работата на машината и чрез прилагане на специално разработен за целта подход е проведен качествен анализ на наблюденията. С помощта на установените фактори и тяхното влияние върху работата на машината са формулирани някои изводи и идеи за техническото ѝ оптимизиране в бъдеще.

Introduction

The interest in the hydropower industry for the use of very low heads (i.e. less than 2.5 m) is growing in recent time more and more intensive. On the one hand, this is the result of the ever-growing energy needs of our society. On the other hand, renewable energy sources become increasingly more important. In the field of hydropower, the range of the very low head differences remains in fact unused. The reasons are numerous and diverse. Now it is important that the existing hydropower potential in this head range in Europe amounts to several hundred MW, and the question of the use of this potential becomes increasingly up-to-date. Important feature of this problem is that the application of conventional water turbines for such very low heads is in principle not feasible.

In this connection, it was the main goal of the four-year research project HYLOW in the 7th Framework Programme of the European Commission (completed at the end of February 2012) to develop, study and test a new power converter for very low head (i.e. 0.5 – 2.5 m) [1]. As part of this project, the Hydrostatic Pressure Machine (HPM) was developed, theoretically justified and extensively tested under laboratory conditions [2,3,4]. On the next stage of development, the HPM prototypes were tested on a larger scale in nature and in the sense of real functioning small hydropower plants. In fulfilling this task, a middle-scale HPM was installed in Partenstein in Germany [1] on a mill channel, and a research small hydropower plant with a full-scale prototype of the HPM was built on the river Iskar in Bulgaria [5]. These activities were intended for construction and operation of complete small power plants with the HPM comprising all necessary equipment components. These power plants were run under different real operating conditions and therefore allowed decisive conclusions about the actual possibilities for industrial implementation of the HPM.

The small water power plant with HPM on river Iskar (Bulgaria)

The main system parameters and considerations in the design and construction of the research power plant with the HPM on river Iskar were already presented in [5,6]. However, this description covered the time up to completion of the structural design and construction activities for the site components and the factory assembly of the machine unit with the HPM. The installation of the equipment on site, the commissioning of the entire system, the setting of the power plant operation under real conditions and carrying out of the test measurements in the frame of the research program were then performed later and reported in [7,8,9], respectively.

The present paper discusses qualitatively some physical phenomena connected with the performance of the HPM under different conditions. These phenomena were observed while the main factors with decisive influence on the HPM performance were altered during the measurement tests. These changes, in turn, led to the identification of different physical operational phenomena some of which could not be predicted theoretically due to the extremely complex spatial character of the fluid flow and the dynamic fluid-structure interaction between the water flow and the rotating wheel of the HPM.

Influencing factors and operational phenomena

The following impact factors have been identified as more or less decisive for the actual performance of the HPM:

- *downstream water level*: The downstream water level of the HPM is of decisive importance for the outflow conditions, i.e. for both machine head and interaction between the out coming wheel blade and the water flow. In fact, a sharp-crested measuring weir was installed in the outflow canal which decreases the possible range of water levels in this canal for different discharges.
- *speed of rotation*: The speed of rotation of the HPM wheel determines the flow rate through the machine and also proved to be of crucial importance for the in- and outflow conditions.
- *upstream water level with respect to the upper end of the hub*: On the one hand, the upstream water level is one of both working head determining components. On the other hand, the position of it strongly affects the inflow conditions of the machine wheel.
- *form and slope angle of the wheel blades*: the actual structure of the HPM wheel blades as well as their spatial form and arrangement affect both in- and outflow conditions by amplifying (or not) some of the observed phenomena discussed below.
- *width of the HPM wheel*: The width of the HPM wheel together with the upstream and downstream canal arrangements in layout strongly influences the water flow character and parameters. In this connection, the comparative analysis with the installation in Partenstein (Germany) [1,4] could serve well the experience in the design of further applications.

The following physical phenomena have been observed during the HPM operation over the whole possible range of conditions of practical importance:

- *movement of the wheel blade out of the water at the down-stream side of the HPM*: The emersion of the wheel blade out of water at the HPM outflow and the physics of the related fluid-structure interaction, respectively, influence the overall performance of the machine and its efficiency.
- *filling of the chamber between two wheel blades with water at the upstream side of the HPM*: This very complicated spatial flow including dynamic interaction between the inflowing water and the blades of the rotating HPM wheel shows different structural levels of the phenomenon itself.
- *water surface curvature at the upstream side of the HPM*: This effect is caused by both particular upstream water level and the complicated interaction between the water flow and the rotating machine.
- *air entrainment due to the wheel rotation at the upstream side of the HPM*: This is a phenomenon which was observed at specific combination of rotation speed and upstream water level and obviously affected the HPM efficiency, too.
- *movement of the wheel blade into the water at the upstream side of the HPM*: This effect is connected with the previously mentioned one of filling the space between two adjacent blades. However, the immersion of a wheel blade itself into the inflow canal can be separately analysed in connection with some additional performance effects.

All above mentioned impact factors and observed operational phenomena under the conditions of particular sets of key parameters form in fact a matrix of dependencies in terms of which the qualitative analysis of the HPM operation below was performed. Thus, the physics of the identified phenomena in the HPM operation was traced in the following with respect to the corresponding sets of the mentioned influence factors. Of course, all described flow and interaction phenomena and the factors of influence are physically interrelated. However, for the aim of clearer structure of the presentation they are discussed further separately.

Movement of the wheel blade out of the water at the down-stream side of the HPM

The emersion of the HPM wheel blades from the downstream water represents physically an important feature of the machine performance due to several reasons. On the one hand, the downstream water level determines the working head of the machine. As already mentioned, the water level in this case could change in a relatively small range due to the actual possible variation of the discharge. On the other hand, the fluid-structure interaction between the moving blades and the water flow causes two interesting phenomena observed during the machine operation:

In fact, the moving up blade lifts some amount of water, **Figure 1**. Although this phenomenon is only of local impact, it is clear that the weight of this water volume (although relatively small) acts negatively on the machine performance since this force acts against the direction of wheel rotation. In this connection, it is also clear that the higher the downstream water level, the stronger this effect is featured.

For a very particular set of water discharge, downstream water level and speed of wheel rotation, a standing wave in the outflow canal can be observed, **Figure 2**. This wave forms parallel to the canal axis and has a relatively small height. It is especially interesting that only the second eigenform of the water body was observed, Figure 2. Unfortunately, at this stage of operational experience no further statement can be made about this phenomenon whose appearance is very sensitive to the above mentioned parameters.

Filling of the chamber between two wheel blades with water at the upstream side of the HPM

The mechanism of filling the space between two adjacent HPM wheel blades at the upstream side of the machine depends strongly on the upstream water level and the speed of rotation. Of course, the form and slope of the wheel blades as well as the width of the inlet canal / chamber additionally amplify or not the observed inflow conditions.

At high upstream water level and low speed rotation, a transverse (rigorously – diagonal, but at almost right angle) to the main flow direction inflow into the space between two blades forms, **Figures 3 and 4 (figures from 1 to 6 are shown on second cover page).** Moreover, an energy dissipation flow mechanism develops during this filling process, **Figure 4.**

However, this phenomenon cannot be observed at low upstream water level when the described filling process is qualitatively different, **Figure 6.**

Water surface curvature at the upstream side of the HPM

Furthermore, at higher upstream water levels and low rotation speed of the HPM wheel, a clearly expressed curvature of the water surface in the inflow canal (chamber) develops, **Figure 3**. In fact, this phenomenon represents the water flow deceleration at the upstream side of the HPM, i.e. the “weir” action of the wheel. The lower the rotation speed and higher the upstream water level, the stronger this feature is presented.

Air entrainment due to the wheel rotation at the upstream side of the HPM

At high rotation speed of the machine wheel, an intensive air entrainment into the water volume of the whole inflow chamber in the vicinity of the HPM can be observed, **Figure 5**. This process is amplified by lower water levels. Of course, building of a two-phase flow domain at the entrance into the machine is not favourable for its performance.

Movement of the wheel blade into the water at the upstream side of the HPM

Together with the emersion of the wheel blades from the water at the downstream side of the HPM, their immersion into the water at the upstream side is an interaction mechanism of decisive importance for the machine performance and efficiency. This interaction qualitatively depends mostly on the speed of rotation and the upstream water level. The forming of a transverse inflow for filling the space between two blades at very low rotation speed was discussed above. When the rotation speed is higher, strokes of the immersing blade throwing some water backward at the surface and bringing air into the water can be clearly observed, **Figure 5**. Of course, this “pumping” action at the upstream side of the machine (although of a relatively small magnitude) acts against its main performance. When both the upstream water level and the rotation speed of the wheel are low, the described negative effect is considerably smaller, Figure 6.

Conclusions

The following conclusions can be drawn from the observed physical phenomena and the performed qualitative analysis of them with respect to the HPM performance and efficiency:

- the design and the resulting in- and outflow conditions of the HPM wheel show some small insufficiencies which affect unfavourable the machine efficiency in terms of interaction of the moving wheel blades with the water flow;

- the HPM wheel parameters (i.e. the form, shape and angle of the blades) enable some negative interaction phenomena, such as air entrainment, transverse flow with energy dissipation and surface strokes which need further research and optimization in the sense of better efficiency;

- some physical phenomena (such as the longitudinal standing wave in the outlet canal) were observed as well which do not affect negatively the machine operation and may have some possible impact only on the performance of water level measuring devices, moreover, only in a very particular operation mode.

All discussed considerations may serve as the base for improvement of the design of the HPM in its further developments. Such improvements can be carried out mostly by re-design (and re-construction, respectively) of the corresponding machine components so that unfavourable interaction processes be decreased or prevented.

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Fig. 1. Water outflow conditions downstream of the HPM

Fig. 2. Standing wave in the outflow canal of the HPM

Fig. 3. Water inflow between the HPM blades and curvature of the upstream water surface

Fig. 4. Water inflow conditions between the blades of the HPM wheel

Fig. 5. Inflow and air entrainment upstream of the HPM

Fig. 6. Immersion of the HPM wheel blades at low upstream water level

КЪМ СТАТИЯ “Observations on the Operation of the Hydrostatic Pressure Machine”