Analysis of the effect of the use of mobile bulb-turbines in the hydropower utilization of the water potential of the Danube River

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***Abstract* - The paper presents a technological analysis of the possible effects of the implementation of mobile bull-turbines in a design solution for the construction of two hydraulic engineering complexes on the Danube: Nikopol-Turnu Magurele (at km 580+650) and Silistra-Cularasi (at km 384+500). The structural and hydraulic characteristics of the Bulb-turbine, as well as its productive and ecological effects contributing to the improvement of the ecological balance in the river basin are presented in depth.**

I. INTRODUCTION

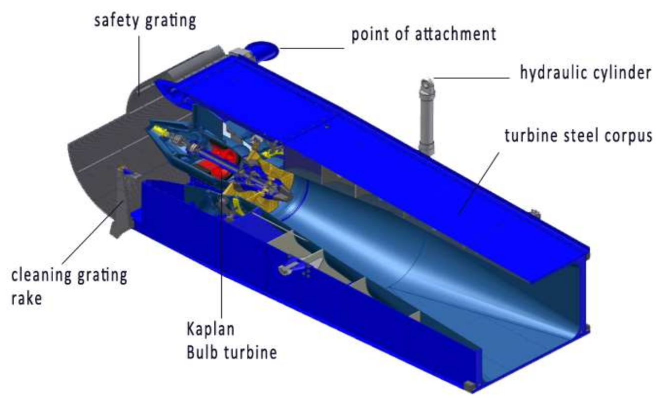
The movable Bulb-turbine is a double-regulated Kaplan turbine. The turbine is particularly designed for working on low and average head (from 2,00 to 10,00 m) and finds its main application in the river-bed power plants. The hydropower plants with installed movable Bulb-turbine differ with a simple construction, easy installation, high efficiency, long-term exploitation and multiple ecological benefits. The hydropower station is completely submerged, which together with the extremely low number of construction and installation activities results in a great reduction of the total project investment costs, as well as preservation of the natural state of flora and fauna in the river ecosystems. The permanent magnet generator is directly connected to the turbine, which results in a very compact and standardized command unit with values of the coefficient of efficiency over 95%.

This is an entirely new concept achieved after many years of research and development. Its objective is to preserve the natural ecological balance in the rivers whilst generating green energy and cutting investment cost to a minimum.

The research in such new technologies has been one of the main priorities of the EU's "Life" Programme established solely for the advancement of environmentally-friendly technologies and making them part of people's lives.

II. CONSTRUCTION SCHEME AND OPERATION OF THE MOVABLE BULB TURBINE

The movable Bulb outstands with an extremely simple construction and easy installation. The hydropower plant is completely submerged, which is a completely innovative and unique conception achieved after numerous scientific studies and experiments. This type of turbines is



specially designed for heads up to 10 m, predominantly in natural river beds. The powerhouse is almost invisible and noiseless, as the noise emissions are reduced to a minimum.

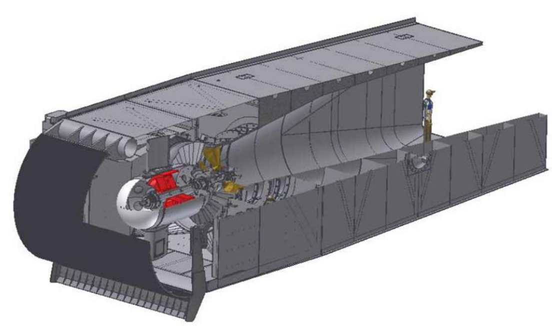
Figure 01. 3-D - CAD model of the structural scheme of a mobile bull-turbine

Figure 02. Example construction diagram of a mobile bull-turbine with characteristics:

Geometric - length: 30m, width: 8,00m, height: 6,00m, total weight: 230.000 kg.

Production - impeller diameter: 4.5 m, stroke: 2 to 10 m, power: 700 to 7.000 kW, for water quantities from 15 to 75 m3/s.

The turbine shall be embedded in a reinforced concrete channel and secured at the bearing connection point. Its movement from one position to another is achieved by means of inox ropes by means of a hydraulic system. The following



photographs represent a computer modelling (simulation) of the construction of a hydroelectric power plant with a mobile bull-turbine.

According to the available water quantity in the river, the turbine operates conditionally speaking in two positions - elevated position and lowered position. When the water quantity is equal to or less than the design water quantity, the turbine operates in the lowered position (Figure 03). In this mode of operation, fish have the opportunity to pass over the structure.

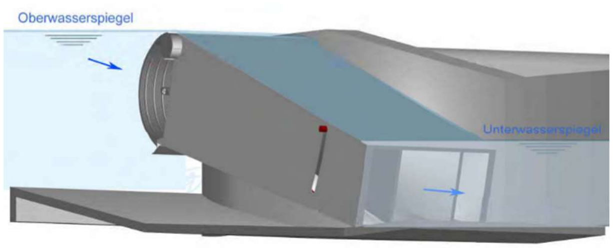


Figure 03. Construction diagram of a turbine operating in a lowered position

At water quantities greater than the design water quantity, the turbine operates in the elevated position (Fig. 04). In this case, not only free passage of floating deposits over the steel turbine casing occurs, but also passage of bottom deposits under the steel casing. In this mode of operation, fish pass both above and below the structure.

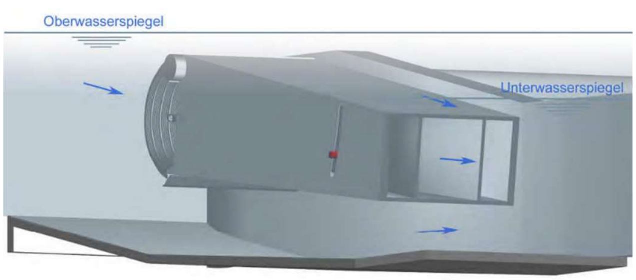


Figure 04. Construction diagram of a turbine operating in elevated position

One of the main advantages of power plants with built-in mobile bull-turbines is the huge reduction of construction and installation works, which greatly facilitates the work on the two hydraulic engineering complexes Nikopol-Turnu Magurele and Silistra-Cularasi. Rough construction work on the building plant practically consists only in making a reinforced concrete channel in which the turbine-generator pair is installed and a bottom plate on which the turbine rests, with water quantities less than or equal to the built-up water quantity.

All reinforced concrete elements of the structure (bottom slab and reinforced concrete channel in which the turbine is located) are calculated according to the current regulations, namely:

A. *Standards for the design of concrete and reinforced concrete structures for hydraulic engineering structures (Publ., BSA, No. 1 of 1989, amended by Order No. RD-02-14-52 of 24.02.1992;*

B. *Standards for the Design of Concrete and Reinforced Concrete Structures (promulgated, State Gazette, No. 17 of 1987; amended, State Gazette, No. 2, State Gazette, No. 17 of 1993; amended, State Gazette, No. 3, State Gazette, No. 3 of 1996; amended, State Gazette, No. 4, State Gazette, No. 49 of 1999; amended, State Gazette, No. 5, State Gazette, No. 58 of 2008), publ. BSA, no. 7/8 of 2008;*

C. *Ordinance No. 3 on the Basic Provisions for the Design of the Structures of the Buildings and the Impacts on Them (promulgated, SG No. 92 of 2004; amend. 98 of 2004; amended and supplemented, issue 33 of 2005); published without amendments, issue 10 of 2004; amended and supplemented, issue 5 of 2005);*

D. *DIRECTIVE No. RD-02-20-2 for the design of buildings and structures in earthquake zones of 27 January 2012;*

E. *Ordinance No. 1 for the design of flat foundations (SG No. 85 of 1996) and Standards for the design of flat foundations; published in BSA No. 10 of 1996;*

F. *Ordinance No. 4 of 15.06.2005 - on technical rules and regulations for the design, construction and use of objects and facilities for the generation, conversion, transmission and distribution of electricity.*

The generator is integrated into the steel turbine housing, which results in an extremely easy construction work and increased efficiency of the production facility. This results in a very compact standardised production unit, which in turn leads to increased production efficiency.

The generator is synchronous, with permanent magnets, and experimental tests show extremely high efficiency, as losses in the excitation system are avoided. Permanent magnet generators allow them to be built into small compact structures while maintaining high polarisation values, which in turn allows them to be connected directly to the turbine without the need for a multiplier. The absence of a multiplier results in very stable and constant generator operation, with virtually no maintenance required. This type of generator is considerably more compact and lightweight than induction generators. They are connected to the grid without the need for a separate transformer. The voltage of the generator can be adjusted by means of a static converter, so that it adapts as well as possible to the mains voltage at the point of connection to the grid. In this way, the optimum voltage curve is achieved, resulting in a significant increase in the efficiency of the generating unit. Under experimental conditions, an efficiency of more than 96% has been achieved at an operating mode of 15% of rated power.

Briefly, the advantages of this type of generators over induction generators can be synthesized in the following order:

- *Higher efficiency;*
- *Smaller size and weight;*
- *Specially designed construction that reduces the total investment costs;*
- *Specially designed seals with greater resistance to axial loads;*

III. Hydraulic characteristics of the mobile Bull-turbine

A characteristic of the mobile Bulb-turbines, as of all Bulb-turbines, is that they can operate over a wider range of water quantity variations. In most cases, the lower limit of their operation is 10%, and the upper 20%, of the nominal water quantity.

Figure 05. Computer simulation of the velocity diagram of an operating mobile bull-turbine in elevated position

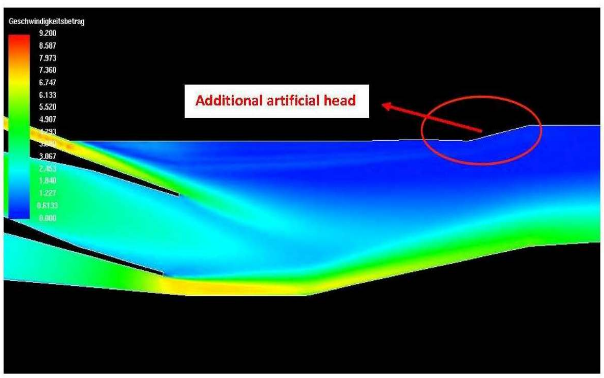


Figure 06. Turbine effect results for 2D and 3D simulation

Being completely submerged under water, the operation of the hydroelectric power plant is characterised by the so-called "turbine effect", which consists in an increase in the velocity of the water after its passage through the turbine, which automatically leads to a further increase in power, creating an additional artificial drop. For small drops, this effect can lead to a 20% increase in total net drop.

When the turbine is operating, the kinetic energy of the water creates an underpressure zone, whereby a suppression of the operating bottom water level (OWL) downstream of the turbine occurs. This is the physical expression of the so-called 'turbine effect'. The optical effect is the 'sinking' of the water immediately after it passes through the turbine. This is the reason that leads to the additionally created artificial sink, in which situation it is possible to reach extremely high efficiency values. The coupling of the water levels, before and after the turbine, takes place with a submerged hydraulic surge. The following pictures show the optical effect of the physical phenomenon in real conditions.

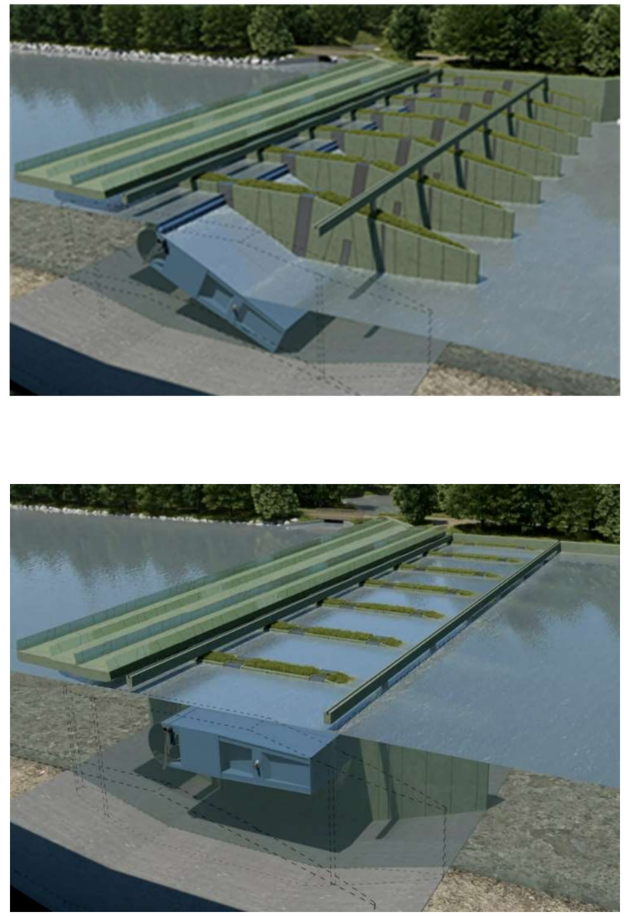


Figure 07. Model of power plant with mobile bull-turbines in normal operating condition and during high water crossing

A major design advantage of hydroelectric power plants with mobile bull-turbines is the fact that in many cases there is no need to build relief structures (spillways) to pass the high waters at high water. The facility passes the high wave freely, including a 1% surge (a 1 in 100 year event - Q1%), freely without any threat to its structural integrity and subsequent normal operation. When extreme water quantities pass, the turbines are in an elevated position, the flanges are closed and the water quantity passes both below and above the turbines.
When designing a plant with a mobile bull-turbine, a physico-mathematical model (Fig. 8) is developed for each specific case by the turbine manufacturer, which reflects the site-specific hydro-dynamic conditions.

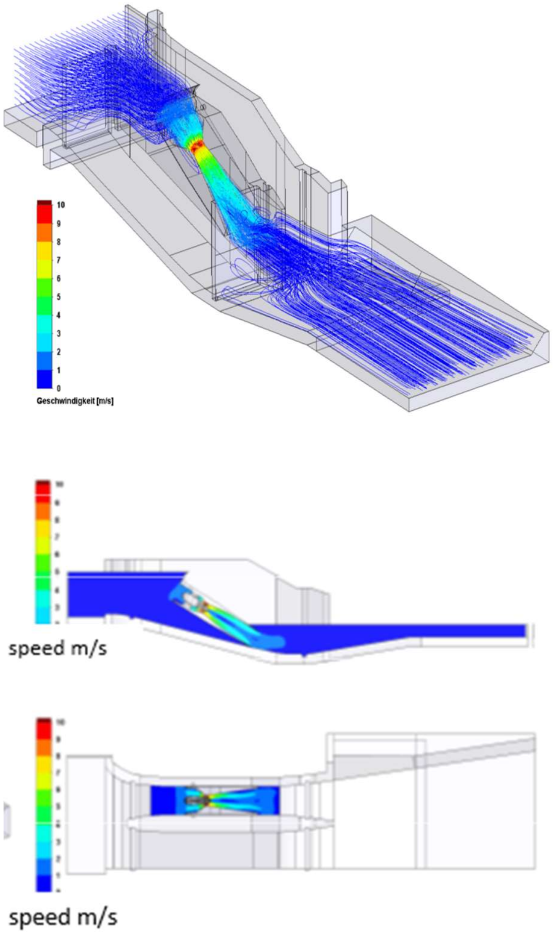


Figure 08. Physico-mathematical model of a mobile bull-turbine

IV. Characteristics of Sediment Transport in Hydroelectric Power Plants with Mobile Bull-Turbine

One of the big environmental advantages of this type of run-of-river plants over traditional ones is that we have free passage of floating and bottom sediments through the facility. The following figures show a computer simulation of floating sediments passing through the hydropower plant. When the grate cleaner is turned on, the floating sediments are further pushed, which facilitates their passage through the facility.

At water volumes greater than the built-up volume, the turbine is in an elevated position, which allows free passage of bottom sediments under the structure. In this way, the natural sediment transport in the Danube river bed is preserved undisturbed. At high water levels, when the turbine is in the elevated position, the water velocity under the steel casing increases. This creates an additional 'suction' effect, which in turn helps the bottom sediments to pass through the facility even more easily.

V. Effect of Hydroelectric Power Plants with Mobile Bull-Turbine on Fish Migration

One of the main goals in designing this type of facility is to make a hydroelectric plant that does not impede the natural migration of fish. In addition to the two fish passes provided for in the Danube hydropower project, this type of facility allows fish to pass both above and below the steel turbine casing. The passage of fish populations below and above the turbine in a functioning hydropower plant has been described and investigated under real conditions.

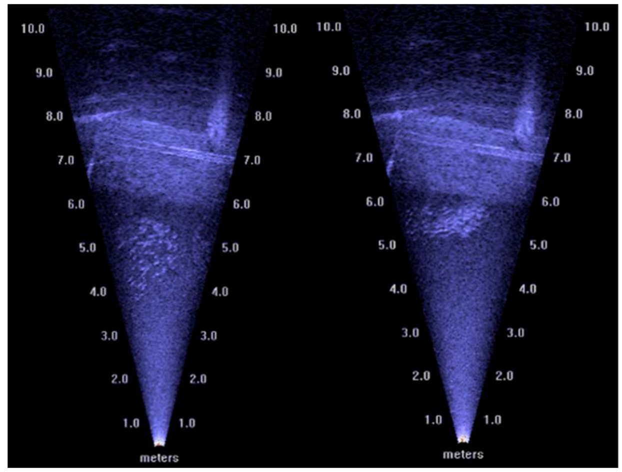


Photo 09. Sonar image of a fish pass passing under the turbine

VI. Mobile Bulb Turbines and the Life Programme

"Life" Programme is a financial instrument that supports sustainable development and implementation of highly innovative green technologies.

Research into such new technologies has been one of the main priorities of the EU's "Life" Programme established solely for the advancement of environmentally-friendly technologies and making them a part of people's lives. The project for Constructing a Movable Hydroelectric Power Plant to Improve the River Environment and Restore the Migratory Patterns of Fish has been funded under reference number LIFE 06 ENV/D/000485. In accordance with Article 4 of Regulation (EC) No. 614/2007, the "Life" Environmental Programme aims to contribute to the development of innovation and implementation of techniques and methods related to the future trends in the development of the European Community's policy for environmental protection. Approximately 1/3 of all "Life" Projects for environmental protection and preservation help the development of green businesses. The project themes developed by beneficiaries under the "Life" Programme touch upon all key environmental challenges typical of Europe such as water conservation, waste management, decreasing air and noise pollution, clean technologies, soil preservation, sustainable usage of resources and decreasing the environmental impact of products by implementing integrated product policies.

"Life" Projects are meant to provide practical and economically viable alternatives to commercial solutions by employing low-carbon and energy-efficient technologies and management methods and addressing important environmental impacts of the process of producing and supplying electricity.

For improved performance in green business operations, the "Life" Programme requires a change in behavior and a commitment to implement practical improvements in environment, such as energy, water and natural resource savings, waste minimizations or reduction in air and noise pollution, for example. These objectives can be achieved through improvements in working methods, but above all, through the development of new technologies.

The first pilot projects for hydropower plants with movable Bulb-turbines are financed namely by "Life" funding instrument and respond to the highest ecological and energy efficiency requirements of the program.

VII. CONCLUSIONS

The advantages of run-of-the-river power plants with installed movable Bulb-turbines in comparison to the conventional type can be summarized in two main categories:

Production advantages:

- lower investment costs on the construction part due to the extremely reduced quantities of construction works, thanks to the absence of a building plant and in many cases of overflows;
- working over a wider range of water availability in the river;
- Increased turbine performance due to turbine effect when running high water;
- Accelerated pace of construction and commissioning of the facility;
- higher efficiency due to the compact machine standardized turbine-generator unit, the lack of a multiplier for connection to the turbine and of a transformer for connection to the power distribution network;
- easier installation and maintenance

Environmental advantages:

- preservation of the natural flora and fauna in the riverbed, thanks to the highly reduced amount of construction works;
- free passage of fish populations above and below the facility;
- passage of floating sediments and small boats over the turbine;
- free passage of bottom sediments beneath the turbine and not impeding natural sediment transport;
- significant reduction *in noise emissions*

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