Design of Machines and Structures, Vol. 15, No. 1 (2025), pp. 70–76.
https://doi.org/10.32972/dms.2025.007

DESIGN OF AN IMPELLER OF PELTON TURBINE

DÁNIEL TÓTH[1], PÉTER BOZZAY[2]

[1]*University of Miskolc, Institute of Machine Tools and Mechatronics,*
H-3515 Miskolc, Miskolc-Egyetemváros
[2]*University of Miskolc, Institute of Energy Engineering and Chemical Machinery,*
H-3515 Miskolc, Miskolc-Egyetemváros
[1]*toth.daniel@uni-miskolc.hu,* [2]*peter.bozzay@uni-miskolc.hu*
[1]*https://orcid.org/0000-0001-8928-4633,* [2]*https://orcid.org/0009-0008-6060-9156*

Abstract: Pelton turbine impeller (often called Pelton wheel or Pelton runner) is the main rotating component of a Pelton turbine, which is a type of impulse water turbine used to generate electricity from high-head, low-flow water sources. The Pelton turbine operates on the impulse principle; water jet strikes the buckets of the runner and the change in momentum of the water jet produces a force that causes the runner to rotate. This article focuses on designing procedures to improve a damaged Pelton impeller.

Keywords: *impeller, scan, Pelton turbine*

1. INTRODUCTION

The Pelton turbine, which is known as an open jet turbine, was designed in 1880 by the American engineer Lester Pelton. As the water is relieved to ambient pressure after emerging from the nozzle, it is also sometimes called a constant pressure turbine (Quaranta & Trivedi, 2021). On the Pelton turbine, the water flows at high pressure and very high speed from one or more nozzles onto the blades of the impeller. Each of the up to 40 blades is divided into two half blades, known as bowls. The flow of water from the nozzles acts tangentially in the middle of these half blades. With a fall of 1000 metres, the water flow can reach a speed of 500 km/h. Depending on the design and fall, the Pelton turbine consumes between 20 and 8000 litres of water per second. It has a very high speed: up to 3000 revolutions per minute. Its efficiency is between 85 % to 90 %, and it achieves high outputs even when not running under full load. It is used in hydroelectric power stations with very high falls and comparatively low volume of water (Bhattarai, Vichare, Dahal, Al Makky, & Olabi, 2019).

2. TEST EQUIPMENT

The Pelton turbine is a widespread, highly efficient hydropower generation device in the field of renewable energy utilisation (Zhang, 2016). For practical education and demonstration of water turbines, a test equipment (see Figure 1) is located at Institute of Energy Engineering and Chemical Machinery at University of Miskolc. One of its modules is a Pelton turbine unit, the operating properties (such as speed, torque, water consumption, etc.) of which can be measured in different operating states using the equipment. The impeller of the turbine is designed in such a way that its operation can be observed with naked eye.

Figure 1. *Test equipment*

The complete impeller of the turbine is a single, injection-moulded plastic part with a complex geometry. During operation, a torque of around 10 Nm can be measured on the brake dynamometer at maximum load. This is a significant strain for a plastic part with such a geometry, and the load –due to the operating principle of the turbine, the varying angle of incidence of the liquid jet and the design of the bucket– varies dynamically, which results in increased strain on the impeller. The combined effect of all of these is likely to have caused the damage to the impeller during operation, the breakage of two buckets, but as a result no other structural elements were damaged. Figure 2 shows the damaged impeller and the broken bucket.

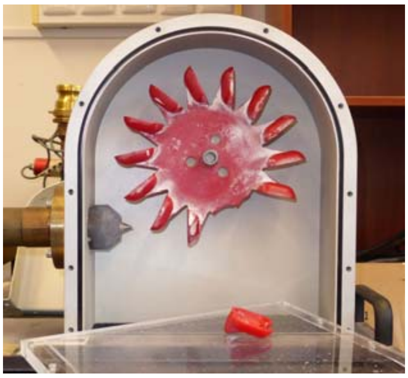

Figure 2. *Damaged impeller*

3. Design of an impeller

Since the damaged Pelton runner rendered the test equipment unusable, the goal was to model and manufacture an impeller like the original. 3D scanner is a device that analyses a real-world object or environment to collect data about its shape and surface appearance. Breuckmann Smart Scan 3D-HE optical scanner (see Figure 3) located at Department of Machine Tools at University of Miskolc, which was used to scan the damaged impeller. The scanner works in the range of visible light and collects information about the surface of impeller by non-contact sampling. The images taken one after the other are stitched together, so we get a complete 3D image of the body to be scanned.

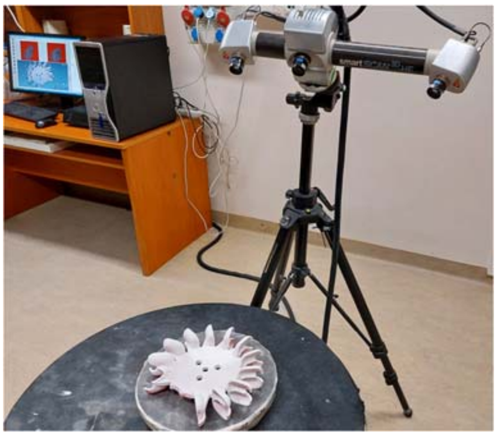

Figure 3. *Scan of damaged impeller*

After the scan, a common section of the images in the field of view of the camera system is displayed on the computer. The images taken one after the other are placed in the Optocat software's own global coordinate system, so they have a different orientation than the recordings of the previous scans. The software does not automatically join the images, this task must be performed manually (Tóth, 2022). In every case, the more recent pictures must be matched to the previous shots to get the full body model. Stitching is done using markers, as shown in Figure 4. The scanned model (see Figure 5) saved in a suitable file format for a CAD software.

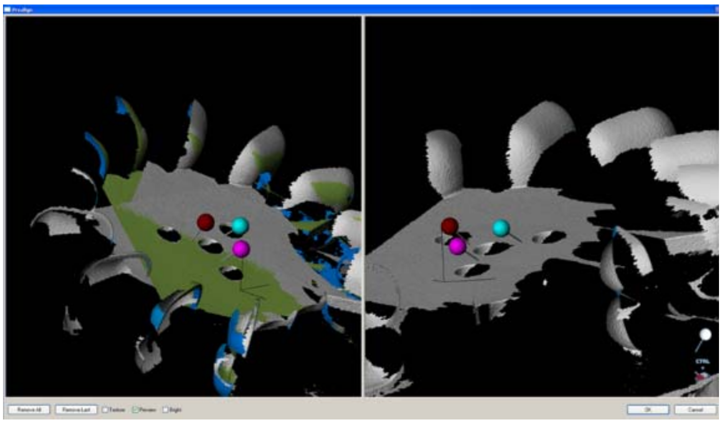

Figure 4. *Stitching scanned images*

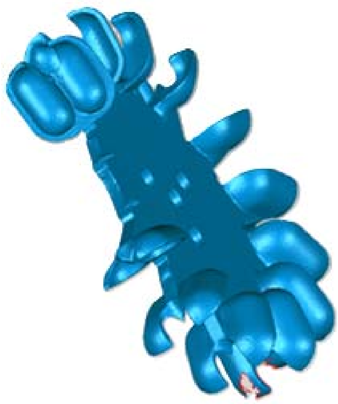

Figure 5. *Scanned 3D geometry of impeller*

There are many CAD software tools available for 3D modelling, with design and functionality depending on the subject and purpose of the design task. For precise engineering tasks –such as the design of this impeller– the use of engineering software supporting parametric modelling is necessary. When designing the impeller, the ability to mount the buckets was an important consideration, so designing the hub was the first step (see Figure 6). After that the bucket was designed (see Figure 7).

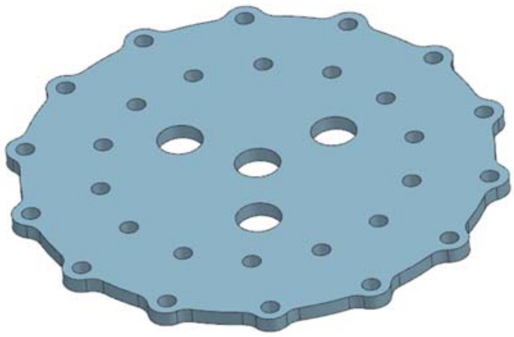

Figure 6. *3D model of designed hub*

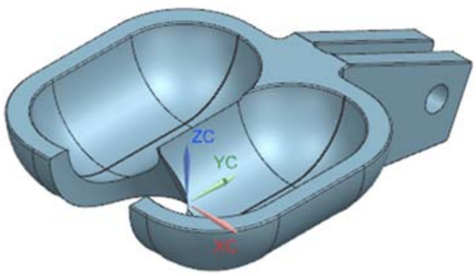

Figure 7. *3D model of designed bucket*

After designing the hub and the bucket, an assembly was made from these, from which a model of the finished impeller was created. Figure 8 shows the assembled impeller. The geometry of the designed model shows a good match with the scanned model.

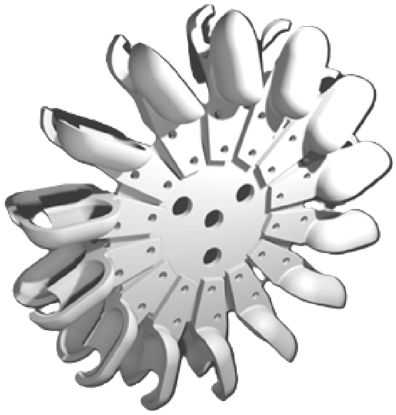

Figure 8. *Assembly of designed impeller*

Rapid prototyping processes provide a fast and inexpensive alternative for producing prototypes and functional models as compared to the conventional routes for part production (Cooper, 2001). Although the technology does not allow to produce parts with the strength required for this real-world task, it is fully suitable for creating tangible, testable and verifiable elements (dimension accuracy, assembly, collisions, joints, etc.). The tool used to produce the prototypes was a Creality Ender-3 V3 KE 3D printer. The printed prototypes (see Figure 9) were made of black PLA material, only two pieces of buckets were used as a test. It can be stated that the size and shape, fit, and drilling of both the bucket and the hub are correct, and no collisions or assembly problems have arisen.

Figure 9. *Prototype of designed impeller*

4. Summary

This article demonstrates that reverse engineering technology can be used to effectively redesign and reproduce a damaged impeller. Results show that the parts produced from the 3D models in a correct quality are expected to be suitable for replacing the original impeller of Pelton turbine. In case of the bucket, further investigation is required to determine whether the quality of the suitable 3D printing technology allows the production of parts with the appropriate strength and surface quality, or whether an alternative manufacturing technology may be required. The impeller designed with individually replaceable buckets, which differs from the factory design, provides a flexible and cost-effective solution in case of a failure.

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