David Tomás Sánchez Martínez
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Proceedings of the 7th International Seminar on ORC Power Systems

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ADDITIVE MANUFACTURING FOR FAST PROTOTYPING OF A VELOCITY COMPOUNDED RADIAL RE-ENTRY TURBINE

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ABSTRACT

In order to achieve a drastic reduction in CO_2 emissions to limit global warming, it must be possible to globally cover the electricity demand from renewable sources. However, the fluctuating availability of solar and wind energy will nevertheless make it necessary to complement the renewables by thermal power plants. Additionally using e.g., the potentials of waste, biomass or waste heat from industrial processes locally in Organic Rankine Cycle (ORC) power plants is a promising approach to finally achieve a stable and sustainable electricity supply. In the present work, therefore, different variants of a radial, velocity compounded re-entry cantilever turbine (Elektra turbine) are investigated regarding their potential for such applications. The paper concentrates on the fast prototyping of an existing 5 kW air turbine demonstrator, recently developed by the authors, by using the possibilities of additive manufacturing with plastic materials to substitute essential parts of the flow geometry. In this context the approach to implement the plastic parts in the turbine is explained. Experimentally determined efficiency parameters of various 3D-printed deflection channel modifications and a printed plastic wheel made of PA12GB are presented, discussed, and compared to the fully milled metal turbine. This results in a quantification of the additional losses due to the higher inaccuracies and roughness of the printed parts, which can be taken into account in further investigations. Furthermore, the various problems and hurdles that must be observed when using 3D-printed plastic parts in high-speed turbomachines are highlighted. With regard to the rotor wheel, the authors conclude that the use of additively manufactured plastic wheels is only feasible with increased preliminary testing. The time required for this is usually not in proportion to the manufacturing time and costs saved. For the stator parts however, 3D-printing turned out to be a reasonable approach.

1 INTRODUCTION

A worldwide shift away from fossil fuels like coal and oil is imperative to address the climate change. In this context, more and more politicians, industry and households recognize the value of renewable energy sources and of a distributed electricity and heat generation that can be adapted to demand, as this ensures sustainable and independent security of supply. Apart from wind and solar energy, that due to strong fluctuations cannot provide all the necessary electricity supply, thermal power plants will still play an important role in the future. However, these future thermal power plants will rely on renewable energy sources like for example, geothermal sources, biomass or waste heat in general. The latter are available decentralized, for example in industrial plants or households, and in small power units. To make these distributed sources usable, thermal power plants that operate in the range of a few megawatts, a few 100 kilowatts or even less than 100 kW_{el} are required. For this purpose Organic Rankine Cycle (ORC) plants based on turbines as expander are suitable (Weiß, 2015). As the energy sources are available in various forms and in different quantities, turbines for these plants must be easily adaptable to different applications and profitable in terms of specific costs. For such small outputs, however, the components of large steam power plants (10 - 1000 MW) cannot be just easily scaled

down, which is why alternative energy conversion machines must be used or developed for this purpose (Weiß *et al.*, 2020). In this context the present work deals with the experimental investigation of a radial, velocity compounded re-entry turbine, the so-called Elektra turbine, patented as "Elastic Fluid Turbine" by (Kolb, 1907).
In the opinion of the authors, this type of turbine seems promising for an application in small-scale ORC power plants as the requirements and framework conditions have changed compared to recent decades. At the beginning of the 20th century, velocity compounded re-entry turbines, like the Elektra, were widespread and were produced in Europe by various companies (Meuth, 1910). As early as (Stodola, 1905), among others, presented results of a 30 kW Elektra turbine with a rotational speed of about 3,000 rpm. These simple turbines were used as direct drives for fans and pumps on ships and their exhaust steam could be reused for preheating in the ship's steam propulsion system. Accordingly, the efficiency of these turbines was not crucial. Due to the increasing demand for energy and the resulting emergence of ever larger, centralized steam power plants, the Elektra has been nearly forgotten since the 1960s.
The aim of our research team is primarily to improve the isentropic expansion efficiency of a 5 kW Elektra turbine demonstrator operated with compressed air by optimizing the flow-mechanically effective geometries. For this purpose, the geometry of an Elektra turbine already designed, manufactured and investigated in earlier studies of the authors (Weiß *et al.*, 2020; Weiß *et al.*, 2022) is adapted for the use of additive manufactured plastic flow guiding geometries in order to enable a fast and easy prototyping and quickly identify further potentials for improvement on the laboratory's own compressed air test bench.
The Elektra turbine belongs to the genus of impulse turbines. With the help of Figure 1, the essential components and the functional principle of the Elektra turbine are explained. It is characterized by the fact that the energy of the gaseous working medium, flowing into the turbine at (a), is almost completely converted from high pressure into high velocity in a supersonic nozzle (Laval nozzle (c)). The resulting kinetic energy is then converted into mechanical work in only one impeller by radially passing through it several times from both sides. Therefore, the flow is alternately reversed and guided back through several deflection channels (d, e, f). The turbine shown works with four-wheel passes and thereby with four velocity stages. This concept is called velocity compounding. 14

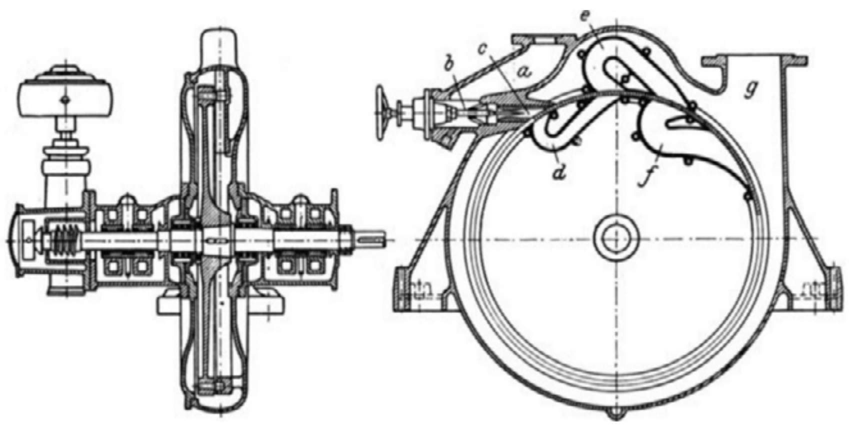

Figure 1: Exemplary structure of an Elektra turbine; a turbine inlet; b nozzle needle; c nozzle; d, e, f deflection channels; g turbine outlet (Pfleiderer and Petermann, 1991)

In order to have space for several deflection channels, the turbine is partially admitted. That means only a small area of the impeller in relation to the circumference is directly impinged by the nozzle. Also, the coverage by the other wheel passages is relatively small. This is possible because the pressure is already completely converted into velocity in the nozzle, which means that there is no more pressure drop over the rotating blades. The wheel diameter can thus be increased, without the need to reduce the blade heights too much, according to the requirements. This is only limited by the available installation space, whereby very low rotational speeds can be implemented. (Zietemann, 1930)
The Elektra concept is right now no longer state of the art and has no more fields of application. However, the authors want to prove that this kind of turbine has potential to contribute to a distributed

electricity generation in the power range of a few kilowatts. Initial results of a numerical and an experimental investigation of the Elektra, discussed and further developed in this paper, were already published in (Weiß *et al.*, 2020). Also the Laboratory of Turbomachines at the Eastern Bavarian Technical University of Applied Sciences Regensburg collaborates with our team in developing a new, advanced Elektra turbine (Janischowsky *et al.*, 2022).

The Elektra has some outstanding properties that make its use in modern small-scale power plants appear sensible. Since the specific acquisition costs [€/kW] are much more important than the achievable efficiency in the power range < 100 kW_{el}, the Elektra turbine is predestined for such applications (Zietemann, 1930). The waste heat from the turbine can still be used on site for heating or cooling purposes, which is why the low efficiency of the Elektra does not have to be a serious disadvantage (Weiß *et al.*, 2020). Depending on the number of velocity stages, rotational speeds of 3,000 rpm or lower can be implemented with the Elektra concept. This makes it possible to apply commercially available standard generators (1,500 – 6,000 rpm). Until now, turbines generally require an expensive high-speed generator and frequency converter, which contribute about 2/3 to the specific cost of the entire turbogenerator (1,000 – 1,500 €/kW_{el}). (Weiß *et al.*, 2022)

Of course, volumetric expanders like scroll, screw or rotary vane expanders can easily be implemented with a rotational speed of 3,000 rpm and similar expansion efficiencies like an Elektra turbine. However, the basic architectures of positive displacement expanders are more complicated. Screw expanders consist of two rotors i.e., they need four bearings and a clutch to the generator. Rotary vane expanders are equipped with sliding vanes which generate friction and suffer from high wear – also a clutch is needed. The single Elektra wheel can be mounted directly on the generator shaft. This is also possible for a scroll expander. However, like for the other volumetric expanders, the built in volume ratio (<< 10) of scroll expanders limits their application to rather low temperature ratios in ORC. Furthermore, all positive displacement expanders need lubrication which spoils the organic working fluid. All these disadvantages do not apply to a turbine. (Weiß, 2015)

However, the question of whether an Elektra turbine can be implemented that directly drives a standard generator and at the same time achieves a still acceptable isentropic expansion efficiency must be clarified. The early Elektra turbines achieved efficiencies well below 50% at outputs of around 30 kW (Stodola, 1905; Meuth, 1910). In this context, the question also arises at what power levels these requirements can be met. The Elektra can only be used sensibly in a power range < 100 kW_{el}. The smaller the nominal power required, the more the advantages of the Elektra concept over standard turbines come into play. (Weiß *et al.*, 2022)

With the methods of computational fluid dynamics (CFD), computer-aided investigation options and improved manufacturing processes available today, it should be possible to develop significantly better turbines than it was the case in the first half of the 20th century. In addition, additive manufacturing in combination with plastic materials offers enhanced possibilities for the development of modern Elektra turbines. Therefore, it is used in this work to test various versions of an Elektra turbine on the test stand.

2 MATERIALS AND METHODS

The investigation of the Elektra turbine presented in this publication directly follows on from the findings in (Weiß *et al.*, 2022) and (Weiß *et al.*, 2020) and continues this work. Accordingly, this investigation also follows the same design process as presented in (Weiß *et al.*, 2022). The difference to previous studies is that the hurdles for manufacturing and experimental testing have been reduced due to the use of additive manufacturing.

2.1 Elektra Design Tools

In the scope of the Elektra investigation, different design tools were used, which were already described in detail in (Weiß *et al.*, 2022) and will therefore only be listed. The design process of the Elektra turbine under investigation began with the predetermination of the geometry parameters using an in-house one-dimensional turbine design tool (1DTDT), which enables a rapid calculation of the geometry data, power output and turbine efficiency for various turbine types. Table 1 illustrates the most important characteristics of the investigated Elektra turbine, which also served as input data for the 1DTDT.

Table 1: Input data for the 1DTDT with values for the Elektra turbine (Weiß *et al.*, 2022)

Input data	Unit	Elektra turbine
Working fluid	-	pressurized air
Total inlet pressure	kPa	1,000
Total inlet temperature	K	≈ 293
Required mass flow rate	kg/s	0.065
Static exit pressure	kPa	≈ 100
Wheel diameter	m	0.08
Rotational speed (Design Point)	rpm	29,000

The 1DTDT provides essential parameters of the turbine flow geometry, like e.g., number of blades, blade angles and channel heights that were elaborated into a complete test turbine. For the numerical optimization, simulations of the flow in the turbine were carried out using CFD. These enabled a fast investigation of various flow geometries before some promising variants were manufactured and measured on the test bench. After identifying optimization potentials, the turbine geometry was adjusted in the CAD program or directly in the CFD environment and iteratively improved. The tool of choice was the Fine^{TM}/Turbo package from Cadence. As the numerical optimization using 3D CFD simulations is not the primary topic of this paper the interested reader is referred to (Weiß *et al.*, 2020; Weiß *et al.*, 2022) for more details on the simulations and mesh design.

2.2 Printing Materials and Methods

The focus of this work lies on the implementation and experimental investigation of several 3D-printed plastic deflection channels and wheels. The aim is to establish a process to enable rapid measurement of different printed geometries and an iterative improvement of the turbine efficiency in experiments. Additive manufacturing is a new technology that finds its way in ever more fields of applications. Especially in turbomachines, there are various potentials to establish 3D-printed parts in the development phase as well as in the final product. The demanding operational conditions, like e.g., high temperatures and pressures and demanding safety standards make an application of printed parts challenging, especially when using plastics (Novotny *et al.*, 2019). However there are investigations done in this field (Hernandez-Carrillo *et al.*, 2017; Spale *et al.*, 2021) and 3D-printed metal parts are already being used in turbomachinery, e.g., for non-safety-relevant parts of aircraft engines. 16

This work was carried out in cooperation with the Regional Technological Institute (RTI) at the University of West Bohemia in Pilsen, which has many years of experience and technical production possibilities in the field of adaptive manufacturing with plastics and metals. Based on this experience, the material PA12GB (40% glass bead filled polyamid) was chosen. PA12GB combines good material properties in terms of tensile strength and machinability, and with the printer used (Hewlett Packard Jet Fusion 4200), high accuracy can be achieved at reasonable cost. This printer has an effective build volume of 380x284x380 mm with a maximal building speed of 4115 cm^3 per hour. It is creating the final part by a multi-agent printing process from a plastic powder. Main advantage is the isotropic behavior of the material and speed of production. Furthermore, no supporting structures are necessary, so the post processing is limited to a minimum. Table 2 shows some essential specifications of the material from the manufacturer's data sheet.

Table 2: Technical specifications of PA12GB (HP Development Company, 2017)

Measurement	Value	Method
Powder melting point	186 °C	ASTM D3418
Density of printed parts	1.3 g/cm³	ASTM D792
Tensile strength, max load, XYZ	30 MPa	ASTM D638
Tensile modulus, XY	2800 MPa	ASTM D638
Tensile modulus, Z	2900 MPa	ASTM D638
Elongation at break, XYZ	6.5 %	ASTM D638
Izod impact notched (@ 3.2 mm, 23°C), XYZ	2.7 KJ/m²	ASTM D256 Test Method A

Heat deflection temperature (@ 0.45 MPa), Z	173 °C	ASTM D648 Test Method A
Heat deflection temperature (@ 1.82 MPa), Z	121 °C	ASTM D648 Test Method A

2.3 Elektra Turbine Design and Methods of Experimental Investigation

The compressed-air Elektra turbine studied here serves as a technology demonstrator on which the development process and tools can be tested and validated, so that they can subsequently be used for the design of larger Elektra turbines in ORC. For this reason, speeds suitable for standard generators (1,500 – 6,000 rpm) have not yet been targeted. This would require four velocity stages and a significantly larger wheel diameter. The turbine investigated in this paper represents the first design of an Elektra turbine of the authors, which is why, for the sake of simplicity, an Elektra with only two wheel passages was investigated. Furthermore, the turbine variants were designed to be tested on the compressed air test stand of the "Turbomachinery" laboratory at the Technical University Amberg-Weiden. Therefore, power and size had to be chosen according to the capacities of the test stand.

Figure 2 b) shows the flow paths of the Elektra version presented in (Weiß *et al.*, 2022). Three nozzles, with an offset of 120° to each other and with an inlet flow angle of 23.07° direct the working medium towards the wheel at supersonic speed. The flow is diverted through three channels, passes the wheel a second time and then flows into the surroundings via three separate outlet areas. The impeller diameter is quite small in relation to the nozzle and channel width. This allows the turbine to be kept compact. However, this also leads to limitations in the dimensioning of the deflection channel. Therefore, they are equipped with splitter blades to improve the guidance of the flow in the channels.

In order to investigate new geometries of the deflection channel faster and easier, a modular structure of the stator was implemented. In addition, the printed wheels could not be mounted directly on the shaft. The different properties of the materials would not guarantee an equal shaft-hub connection compared to the original aluminum wheel and thus the occurring torque cannot be transmitted. For this reason, the wheel is mounted to the shaft via an aluminum adapter on which it can be easily screwed (see Figure 2 a)). 17

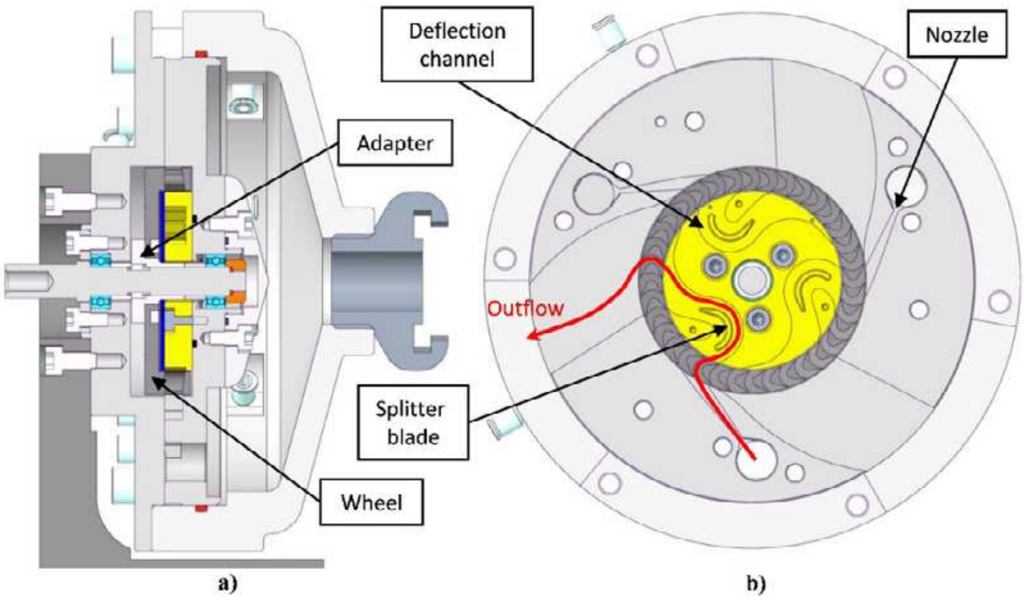

Figure 2: Sectional views of the examined Elektra turbine

Several Elektra versions, also equipped with an additively manufactured metal wheel, were already investigated experimentally on the compressed air test stand. In order not to go beyond the scope of this paper, this will not be discussed in detail. For more information on these versions and the test stand the interested reader is referred to (Weiß *et al.*, 2022). From the evaluation of the measured values obtained for mechanical power, pressures at the inlet and outlet of the turbine, temperature as well as mass flow rate through the turbine, conclusions can be drawn about the total-to-static isentropic expansion efficiency of the turbine configuration.

3 RESULTS

Four different modifications have been experimentally investigated starting from the best performing version (*Version 1*) presented in (Weiß *et al.*, 2022), that is characterized by a milled aluminum wheel and a milled aluminum deflection channel with splitter blades of 1.5 mm thickness. *Version 1* is used as a reference. *Version 2a, 2b* and *2c* have exactly the same flow geometry like *Version 1*, that is shown in Figure 2 b). Differences are the thickness of the splitter blade that is varied from 0.5 – 1.5 mm and the used material, which is PA12GB for the defelction channel. *Version 3* additionally has a printed wheel made of PA12GB in combination with the printed deflection channel with 1.5 mm splitter blades. Figure 3 shows the milled aluminum wheel (Figure 3 a)) and the printed plastic wheel (Figure 3 b)) in comparison for a better understanding of the differences. The printed deflection channels are not graphically displayed, because they have a fixed cover on both sides which means that pictures of it do not add any valuable information. The versions are listed again below with their characteristic distinguishing features:

- *Version 2a*: *Version 1* with printed deflection channel and splitter blade (1.5 mm)
- *Version 2b*: *Version 1* with printed deflection channel and splitter blade (1.0 mm)
- *Version 2c*: *Version 1* with printed deflection channel and splitter blade (0.5 mm)
- *Version 3*: *Version 1* with printed wheel/deflection channel with splitter blade (1.5 mm)

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Figure 3: Comparison of: a) milled aluminum wheel (*Version 2 a, 2b and 2c*) and b) 3D printed plastic wheel (*Version 3*)

3.1 FEM and Modal Analysis of Critical Structures

In order to ensure the usability of PA12GB at speeds of up to 30,000 rpm before the first experimental investigations, finite element method (FEM) simulations of the wheel (Figure 4) and the shaft-hub connection (Figure 5), as well as a modal analysis of the wheel were carried out by the RTI. For the investigations, the software Siemens NX version 2000 with build 3701 was used. The used solver was NX Nastran with solution option solver 101 and solver 103.

The maximum stresses in the wheel are approx. 31 MPa. However, these only occur sporadically at points where no radii were applied in the CAD model. In general, the stresses are well below the load limit of 30 MPa, which makes it possible to use the wheel without any problems. This was also confirmed with a burst test that was carried out on a specially created test set-up, on which the wheel including adapter and shaft was operated at 30,000 rpm outside the turbine in order to avoid damage to the stationary parts. The maximum displacement is approx. 0.29 mm in radial direction, what is in an acceptable range as the gap between rotor and stator is 0.5 mm. In addition to that, a modal analysis of the wheel was carried out. It resulted in a 1. Eigen frequency of the wheel at 837 Hz, which is far away from 500 Hz (30,000 rpm). Furthermore, the designed connection between shaft and hub (adapter with mounted printed wheel) was investigated concerning stress and displacement. Therefore, it was loaded with a torque of 2.5 Nm resulting from former experimental investigations. The maximal stress within the aluminum adapter was 81.76 MPa and 5.02 MPa within the 3D printed wheel (see Figure 5). Both values are significantly below the materials strength limits.

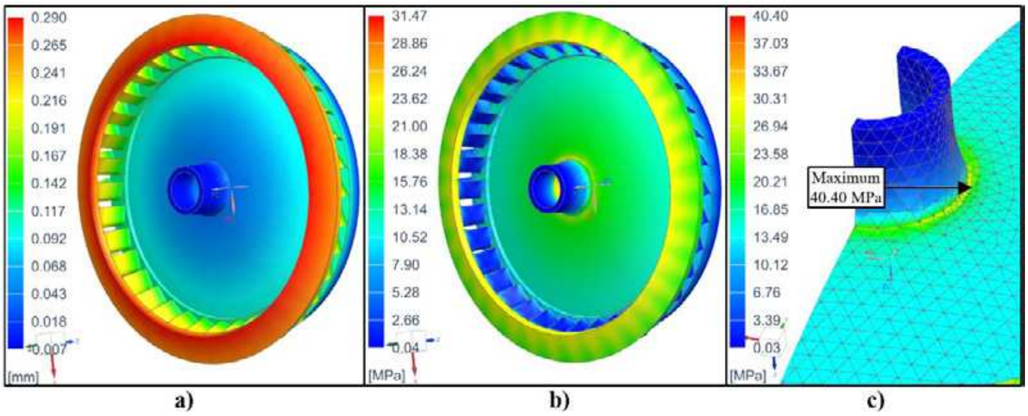

Figure 4: FEM-Simulation results of the rotating plastic wheel at 30,000 rpm: a) Displacement – Nodal Radial; b) Stress Element – Nodal Averaged, Von-Mises; c) Maximal Stress before averaging

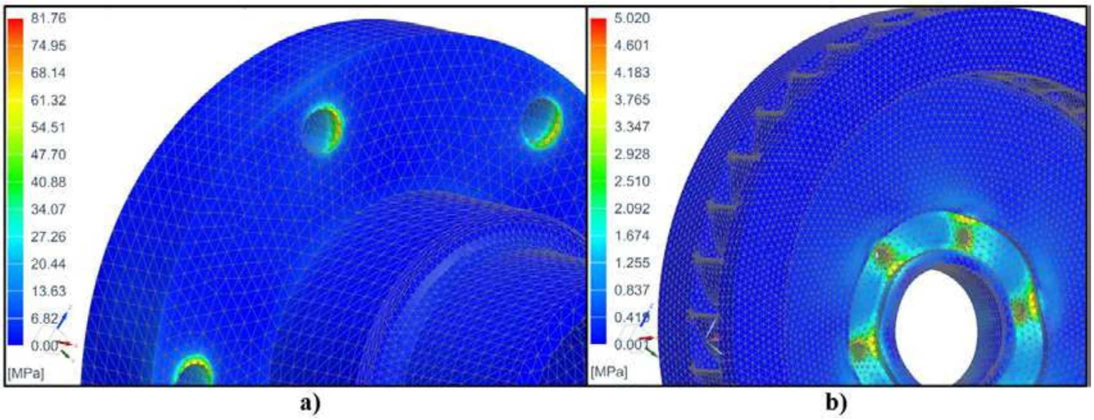

Figure 5: FEM-simulation results of shaft-wheel connection: a) Stress-Element in the adapter – Nodal Averaged, Von-Mises; b) Stress-Element in the wheel –Nodal Averaged, Von-Mises

Apart from that, the different splitter blade thicknesses were checked regarding stresses due to pressure differences in the deflection channel. Therefore, they were loaded with static pressure data from the CFD-simulation. For the printed parts, a cover and therefore a fixed connection between hub and splitter blades is applied. For that reason, no problems regarding the stress in the splitter blades were detected even with only 0.5 mm blade thickness.

3.2 Experimental Investigation

The three printed deflection channels with different splitter blade thicknesses (*Version 2a*, *2b* and *2c*) as well as the printed plastic wheel combined with a printed deflection channel (*Version 3*) were tested on the compressed air test stand. Figure 6 shows the resulting total-to-static isentropic efficiencies as a function of the applied pressure ratios (PR; turbine inlet to outlet) for a constant rotational speed of 30,000 rpm. The maximum measurement deviation of the isentropic efficiency is graphically displayed as an error indicator. The results of *Version 1* (milled aluminum wheel and milled deflection channel with 1.5 mm splitter blades) serve as reference to quantify the deviations between milled metal and printed plastic parts, which were expected due to different surface qualities.

It is obvious, that the rougher surface of the printed deflection channels results in a reduction of the efficiency. In case of the 1.5 mm splitter blade channel (*Version 1*) this deviation to *Version 2a* rises with rising PR starting from no deviation below PR = 6 (deviation within the measuring tolerance) up to approx. 3 $\%_p$ at higher PR's. Surprisingly the reduction of the splitter blade thickness did not reduce the pressure losses. The splitter blade has nearly no influence (comparing *Version 2a*, *2b* and *2c*) on the efficiency for PR > 9. Below that point the deflection channel with 1.5 mm splitter blades (*Version 2a*) still achieves the best efficiencies.

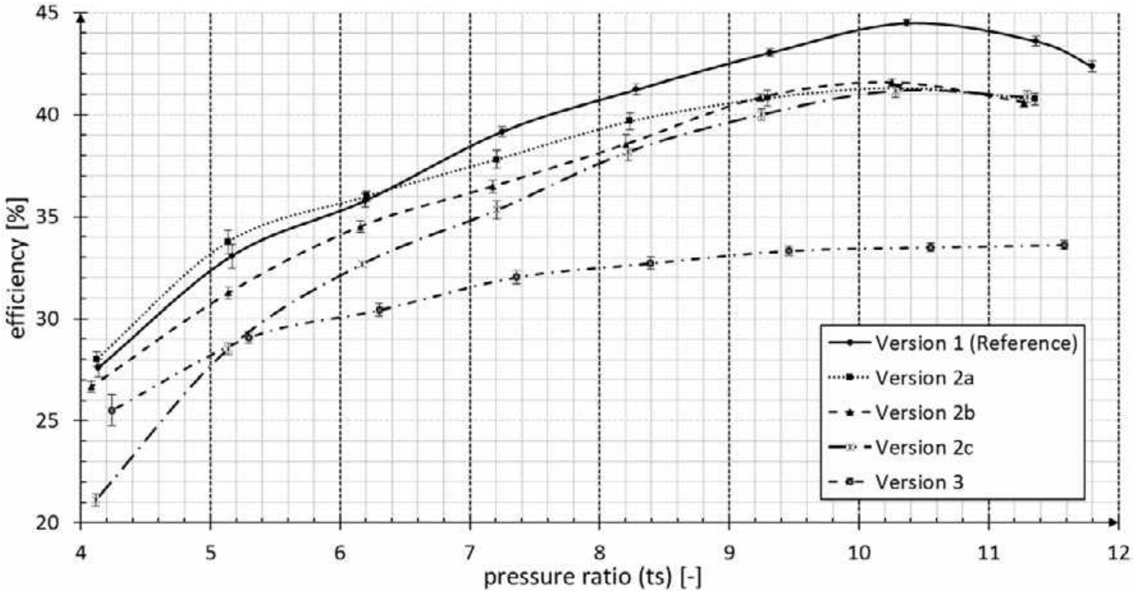

Figure 6: Measured total-to-static isentropic efficiency over PR for different Elektra versions

The flow geometries of the 3D-printed parts made of PA12GB, that could not be reworked after printing, have an average roughness of Ra = 7.8 µm. The relevant surfaces of the aluminum wheel are in a range of Ra = 1.8 µm and the milled channel achieves approx. Ra = 0.4 µm. Figure 7 a) and b) show the surface texture of the 3D printed wheel. The milled aluminum wheel, which was additionally glass bead blasted, shows a much more even surface (Figure 7 c) and d)).

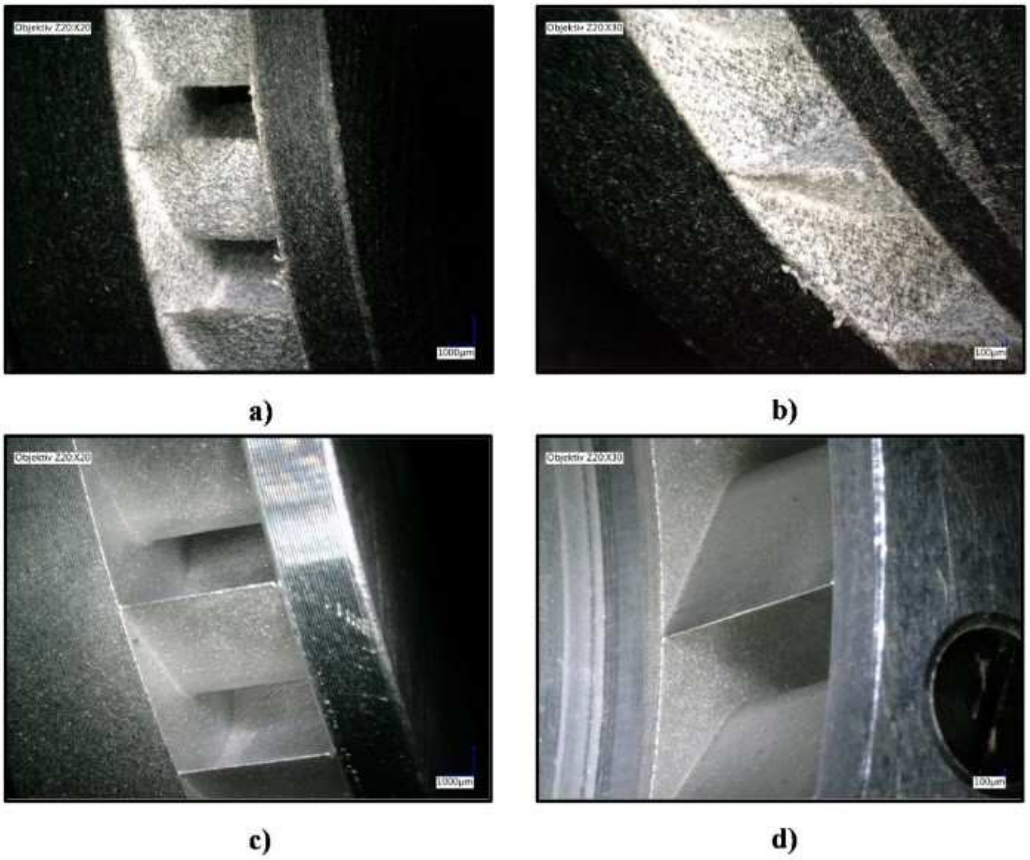

Figure 7: Surface texture of: a) Printed rotor overview; b) Printed rotor detailed view; c) Milled rotor overview; d) Milled rotor detailed view

The testing of the printed wheel (*Version 3*) caused various problems with a view to balancing. Reworking of the material is quite challenging as the plastic tends to smudge if the machining temperature gets too high. The reworking of some surfaces is nevertheless necessary to ensure the required form and position tolerances for a smooth running of the wheel. Furthermore, a tumbling of the wheel due to insufficient plan areas was detected during balancing. Additional balancing of the shaft was required to counteract this. Finally, the remaining static and dynamic imbalances could be reduced to a sufficient balancing grade, to run the printed wheel at 30,000 rpm. Higher rotational speeds could not be tested as the wheel might have been damaged. Nevertheless, the original plastic wheel geometry could be measured in the scope of this work (*Version 3*). Thus, the additional losses compared to the aluminum version can also be quantified here, which are approx. 3.5 $\%_p$ at PR = 4.4 compared to *Version 2a*. They constantly increase up to more than 7 $\%_p$ at higher PR's.

4 DISCUSSION

Additional losses of printed deflection channels due to the inaccuracies and rougher surfaces of the printed parts occur as expected and can now be quantified and factored into testing of further channel designs. The reduction of the splitter blade thickness didn't show the desired effect of increasing the efficiency compared to *Version 2a*. Reasons for that could be different surface qualities of the printed parts depending on position and location in the printer, which might compensate the advantages of reduced pressure losses by thinner blades. For further improvements of the efficiency the geometry changes must be more significant. The use of the printed plastic wheel resulted in a drastic reduction of the efficiency, which can now be calculated into further investigations and might be acceptable if manufacturing is significantly quicker and cheaper. However, it turned out that the unavoidable reworking and balancing of the printed plastic wheels is quite challenging. First, the less isotropic structure of the printed plastic wheel implies more imbalances compared to a milled metal wheel. Second, the fit between the printed plastic wheel and the necessary aluminum hub is crucial. If it is not tight, balancing is not sustainable or even not possible at all. However, the plastic tends to yield to internal stresses caused by the fits to the adapter, which means that the required fits cannot be maintained exactly. Additionally, the axial runout and the tolerances of the abutment surfaces must have the same quality as metal wheels, which is difficult to achieve by reworking. This causes a tumbling of the wheel and therefore a touching of the housing wall mainly in axial direction.

5 CONCLUSIONS

The investigation of the Elektra turbine using additive manufacturing to speed up the design process brought forth some interesting findings. Especially the testing of new deflection channels can now be carried out significantly faster and more cost-effective compared to milled metal parts. However, one must take into account the additional friction losses due to the rougher surface of printed PA12GB that can vary in a certain range. Further tests are required to fully capture these influences. Nevertheless, a further investigation of different stator geometries seems meaningful. However, for rotating parts at these high speeds the "fast" prototyping using additive manufacturing with plastics caused lots of unexpected problems. The time required to achieve a functional turbine structure and to record all the variables influencing the behavior of the wheel is disproportionate to the costs and time saved by fast and inexpensive additive manufacturing. In the opinion of the authors, the investigation of wheel prototypes for high-speed turbines is therefore not sensible. At the actual speeds of 1,500 – 6,000 rpm intended for the Elektra, on the other hand, the use of plastic wheels would be quite interesting. Here, the balancing of a printed plastic wheel should no longer cause problems. However, in a final application, to evaporate the working fluid in an ORC, often requires temperatures at or above the melting temperature of most plastics. This might again lead to problems when using plastic wheels. Regarding the use of the Elektra in modern ORC plants in the power range <100 kW_{el} the authors state, that the limited power and size of the investigated turbine make it difficult to further increase the efficiency of the small 5 kW Elektra demonstrator. In the future, the focus will therefore lie on the development of Elektra turbines that are suitable for use in ORC systems and operate at the targeted rotational speeds. A commonly manufactured metal 7.5 kW Elektra turbine (wheel diameter Ø D = 255 mm) that operates at 3,000 rpm in a woodchip fired combined heat and power ORC plant (working fluid hexamethyldisiloxan) is currently under testing. The results will be published as soon as available.

NOMENCLATURE

CO_2	Carbon dioxide	(–)
ORC	Organic rankine cycle	(–)
3D	Three-dimensional	(–)
CFD	Computational fluid dynamics	(–)
1DTDT	1D turbine design tool	(–)
CAD	Computer aided design	(–)
PA12GB	Polyamid 12 glass bead filled	(–)
FEM	Finite element method	(–)
PR	Pressure ratio (total-to-static)	(–)
Ra	Mean roughness	(µm)

Subscript

el	electric
p	points

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This book contains the compilation of works contributed to the *7th International Seminar on Organic Rankine Cycle Power Systems* (ORC 2023), held in Seville between the 4th and 6th of September 2023. The event was hosted by Universidad de Sevilla on behalf of the Knowledge Centre on Organic Rankine Cycle Technology (KCORC), incorporated in The Netherlands.

The ORC conference, organized biennially, stems as the only conference that is specific to ORC technology, therefore gathering a diverse community whose affiliation spans across all the interested stakeholders, not only in this particular technology but also and in a broader context, in the energy transition. Original equipment manufacturers, professional associations, end-users, investors, policy makers, academics, scientists feel at home at ORC 2023.

The almost 100 proceedings in this book cover a wide variety of topics, from fundamentals to system integration through component design, accounting for thermodynamic performance as well as component design. In addition to this, and as a new track in 2023, works on heat pump technology were also accepted in order to raise awareness of the strong ties between both technologies, specifically in energy storage applications.

This book provides an excellent overview of the current maturity of power systems based on Organic Rankine Cycle technology for applications as diverse as geothermal and waste heat recovery in industry or downstream of other prime movers (e.g., marine applications). It is also an excellent source of information to understand the current challenges faced by the technology, stemming from a very competitive market and increasingly stringent environmental regulations.

The organizers of ORC 2023 hope that the reader finds this work as exciting as the attendees to the conference and, maybe, make the decision to join the 8th edition to the conference in 2025.

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