CUSTOMIZED SMALL-SCALE ORC TURBOGENERATORS

COMBINING A 1D-DESIGN TOOL, A MICRO-TURBINE-GENERATOR–CONSTRUCTION KIT AND POTENTIALS OF 3D-PRINTING

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Outline

1. Introduction
   – why 1 stage impulse turbines for ORCs?
   - need for lowering costs etc.
2. Turbine 1D design tool
   – robust & fast design of customized turboexpanders
3. The Micro-Turbine-Generator-construction-kit (MTG-c-kit)
4. Design example and experimental results
5. Opportunities of additive manufacturing
6. Conclusions

1. Introduction

- Expander is most critical component of the ORC plant
- Turbines vs. volumetric expanders
- Turbines
  - still rather uncommon for micro-applications (rpm, tolerances)
  - single stage preferred (simplicity)
  - 90° IFR turbine most common because availability on market
  - regarded as complicated in design and construction, expensive, unsuitable for small series...

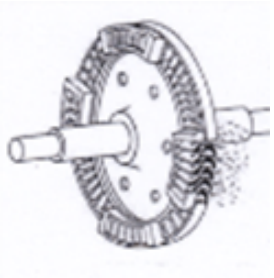
1. Introduction

- Novel concept
  - simple single stage impulse tubines provide flexibility and acceptable performance for most of requirements
  - highly modular system, minimization of adjustments between applications
  - use of simple, appropriate and yet reliable loss correlations

- Outlook – additive manufacturing
  - less waste, digital manufacturing thread,...
  - more customization and faster development
  - for LT applications possibility of plastic materials
  - bringing down costs

2. The 1D-turbine design tool (1D-tdt)

- Developed for axial impulse or radial "quasi-impulse (cantilever)" turbine, axial Curtis turbine and 90° IFR turbine

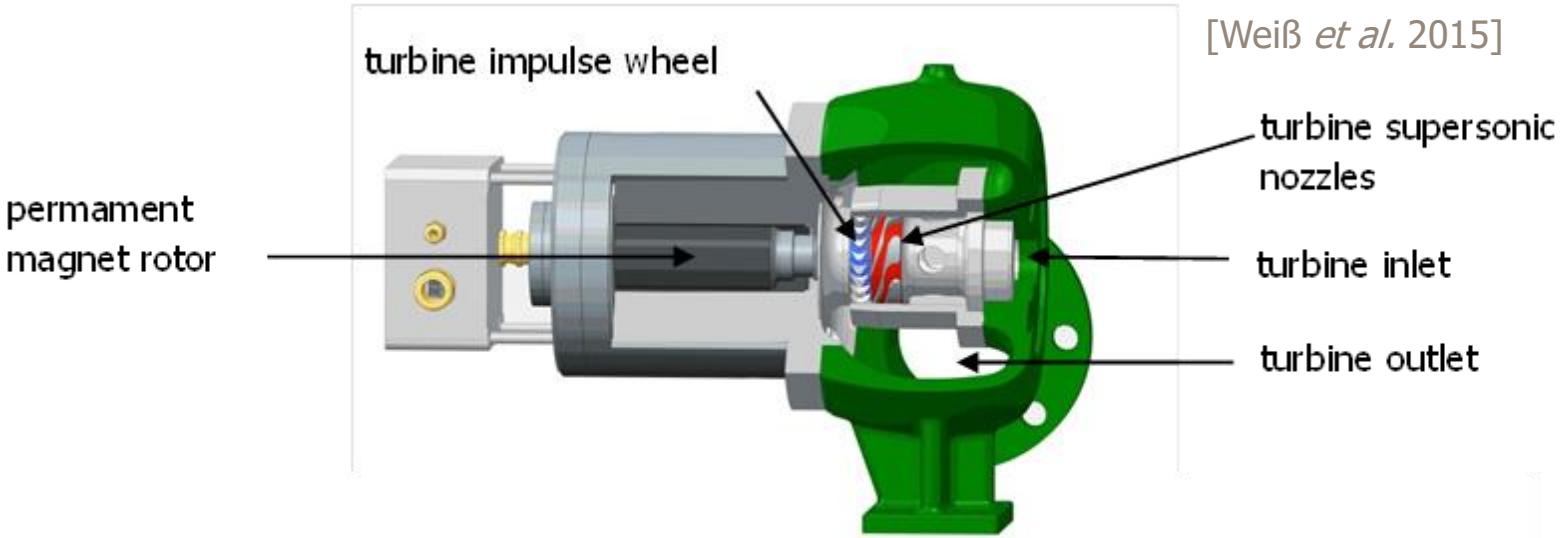



- Specific or "uncommon" design boundary conditions
  - only 1 stage, highly loaded i.e. high pressure ratios or Mach numbers
  - small systems i.e. volume flow rates: low specific speeds
  - classical, open literature loss models (e.g. Traupel, Craig & Cox etc.) not really reliable (Klonowicz *et al.* 2014)
  - therefore, we use experimentally adjusted, in-house loss model based on NASA publications dealing with supersonic turbine drives for rocket turbo pumps

2. The 1D-turbine design tool (1D-tdt)

- Developed and implemented in MS Excel / VBA
- By means of the 1D-tdt we are able to determine quickly the main data like velocity triangles, pressure, temperatures and blade angles and heights etc. of the turbine
  - based on these few data, an experienced designer can build up a 3D model of the turbine in CAD
  - following, the turbine stage is analyzed and optimized in 3D-CFD.
- The 1D-tdt as well as 3D-CFD uses REFPROP. Therefore, turbine design for about 350 fluids is possible.
- The 1D-tdt can be used "by hand" or in a semi-automatic modus in order to search the best turbine out of a pre-defined range of parameters.

3. The Micro-Turbo-Generator-construction-kit



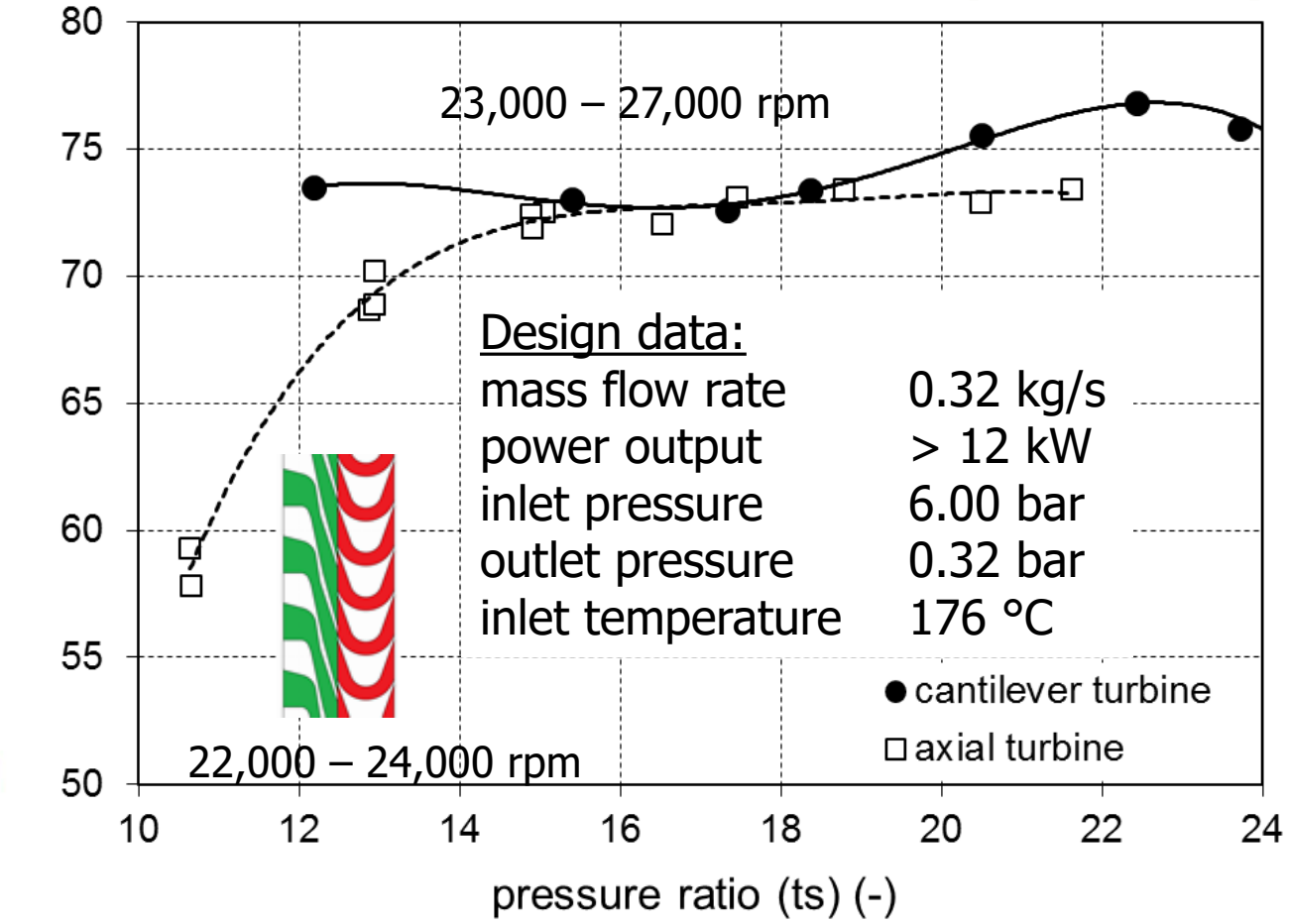
[Weiß *et al.* 2015]

- hermetically sealed turbine-generator (3 - 200 kW_{el} , implemented with 5 different- sizes)
- single stage axial impulse turbine (10,000 – 70,000 rpm) which is able to process very high pressure ratios and small volume flow rate (partial admission)
- integrally manufactured turbine wheel (Ø 50 – 350 mm)
- permanent magnet high-speed generator
- turbine wheel directly mounted on generator shaft: just one set of bearings required, no gear, no coupling
- compact design, low material usage

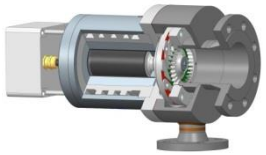
4. Design example and experimental results

Total-to-static isentropic efficiency of an axial and a cantilever turbine for the same boundary conditions (hexamethyldisiloxane)

[Weiß *et al.* 2018]



M_{nozzle} = 2.12
M_{rotor} = 1.13



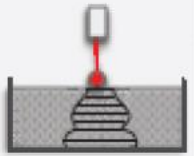
M_{nozzle} = 1.98
M_{rotor} = 0.87

5. Potentials of additive manufacturing

- Intent of improving applicability
- Goals:
  - reduction of specific costs €/kW_{el} by at least 20%, especially for low power applications
  - reduction of manufacturing lead times, including in tests of multiple blading design
  - improvement of the design and customization of blading for specific applications
  - further reduction of the number of components (e.g. wheel with shroud in a single piece)

5. Potentials of additive manufacturing

- Wide range of possibilities (sorting by ISO / ASTM52900-15 standard)

	Material Extrusion	Vat Photo-polymerization	Material Jetting	Binder Jetting	Powder Bed Fusion	Direct Energy Deposition	Sheet Lamination
Scheme							
Process	Layer by layer deposition of molten material	Selective curing of photo-curable material in a liquid container	Material deposition and subsequent curing	Selective dispense of binder for joining powder in a bed	Fusing of powder in a bed by melting the selected region	Direct fusion of the material	Bonding of individual sheets of material
Name	FDM RC MJS SFF	SLA DLP LAMP 2PP	DOD MJ NPJ	BJ	SLS SLM DMLS EBM MJF	LENS EBAM DMT	LOM UC

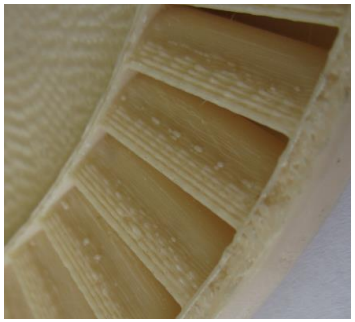
U.M. Dilberoglu, B. Gharehpapagh, U. Yaman, M. Dolen, The role of additive manufacturing in the era of Industry 4.0. Procedia Manufacturing, 11:545-554, 2017

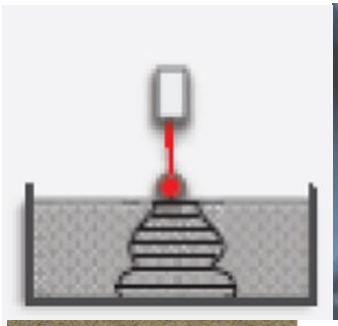
5. Potentials of additive manufacturing

- Fused deposition modelling (FDM)
  - Limited precision & accuracy
    (but available post-processing)
  - Most available and usually cheapest
  - Suitable rather for static parts
  - Wide range of materials

- Stereolithography (SLA)
  - Best surface quality for as-printed parts
    (but leaves burs)
  - Our experience shows poor accuracy
  - Most expensive plastic & limited materials

- Selective laser sintering (SLS)
  - Our experience shows best accuracy
  - Moderate surface roughness (excl. metal)
  - Relatively cheap (also cheapest metal)

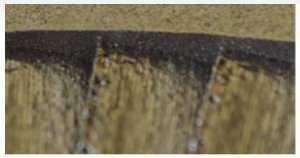
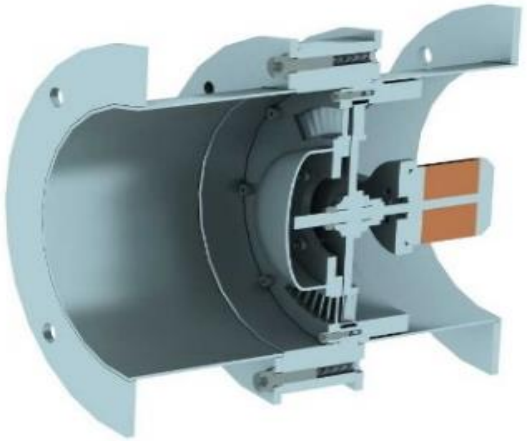
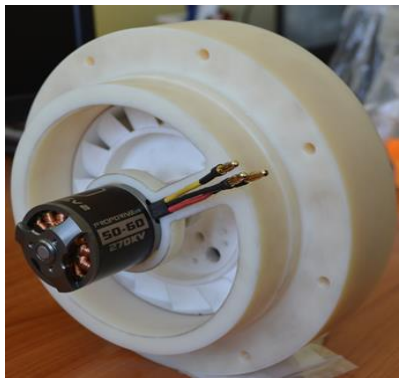


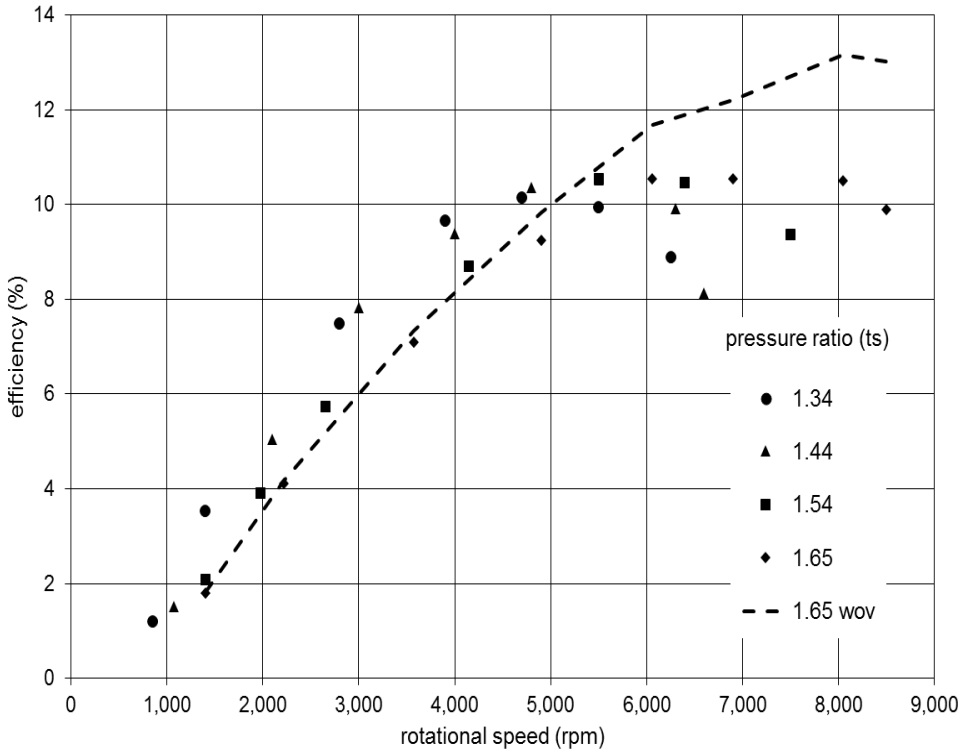
Image courtesy of Siemens

5. Potentials of additive manufacturing

- Our first tests
- Simple air turbine turbine for trials







6. Conclusions

- A 1D design tool with robust correlations can effectively and quickly lead to assessment and implementation of feasible and sensible turbine designs
- Impulse turbine can proove to be a suitable choice for small ORC and similar systems
  - axial as well as radial cantilever type
- Additive manufacturing & plastic materials
  - offer interesting possibilities for low temperature and small applications
  - simple air turbine for trials shows still a large potential for development and improvement

Thank you for attention.

Any Questions?

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