

Energy Harvesting approaches for intelligent Sealing Systems

Marcel Schreiner
Hannover, 7.April 2011



Agenda

1	Freudenberg Company Profile
2	Motivation
3	Ambient Energy Sources in Sealing environment
4	Application Example – Intelligent Simmerring for E-Motor
5	Summary

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The Freudenberg Group worldwide



Overview of selected indicators	2008	2009
Group sales	5,050 million EUR	4,201 million EUR
Group profit	176 million EUR	-250 million EUR
Cash flow from operations	393 million EUR	456 million EUR
Equity ratio	46,9%	44.5 %
Employees	32,738	32,142
Rating	A3	Baa1

Freudenberg Group

Corporate Profile

Business Area Seals and Vibration Control Technology	Business Area Nonwovens	Business Area Household Products	Business Area Specialties and Others
<p>Business Areas</p> <p>Seals and Vibration Control Technology Europe </p> <p>NOK-Freudenberg China</p> <p>Seals and Vibration Control Technology USA</p> <p>Vibracoustic Europe </p> <p>Burgmann Industries </p> <p>Dichtomatik </p>	<p>Business Area</p> <p>Nonwovens</p> <p>Freudenberg Filtration Technology</p> <p>Freudenberg Politex Nonwovens </p>	<p>Business Area</p> <p>Household Products</p> 	<p>Business Area</p> <p>Chemical Specialities</p> <p>NOK Mechatronics</p> <p>IT- Services</p> <p>New Technologies </p>    <p>Business Area</p> <p>Services</p>

Advanced Complete Solutions

for Power Engineering



Simmerring®
Radiamatic



Vibration control



Hydraulic
accumulator



Special sealing
products

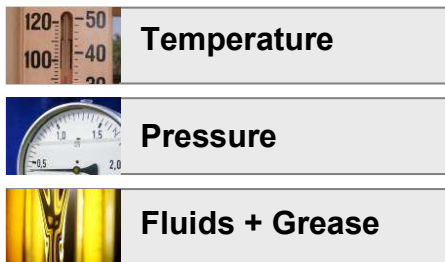


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Motivation

Why combining Sealing with Sensors?



Seals are used in harsh environments
Seals are placed at the spot
Seals often have an A-Function



ECU

- Complexity of electronic components in applications is growing from year to year
- Condition monitoring becomes more and more important
- Sensors are needed today to fulfill the demands of exhaust emission and security
- Some sensors need contact to fluids and gas
- Sensors need space, a borehole, a seal and logistic cost
- Freudenberg seals are often in direct contact to oil, water, etc.



Solution: Smart sealing systems for condition monitoring

Motivation

Energy harvesting

Sealing's are interface components placed at the Spot!

- Space for wiring and additional electronic components is often extremely limited!
- Wiring increases mounting effort!
- Independence from external power supply for internal sensor equipment

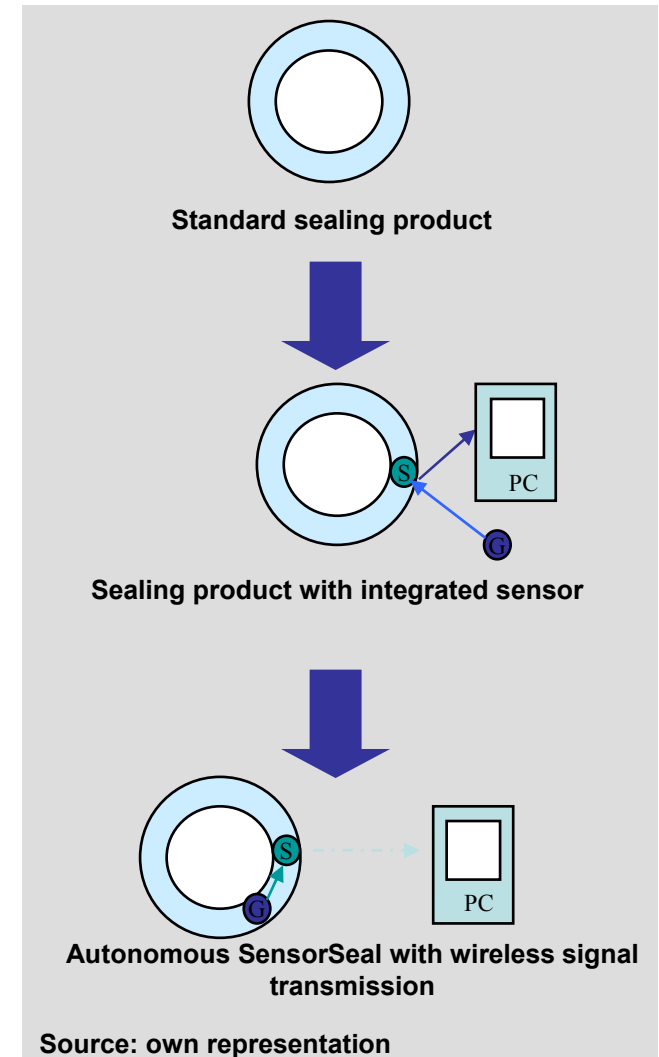
Sealing's are used in harsh environments!

- Harsh means:
 - Changes in Temperature
 - Changes in Pressure
 - Vibration
 - Rotation

- ⇒ Different energy sources for harvesting are available!
- ⇒ Batteries are difficult to apply!

New areas of application for existing sealing solutions!

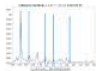
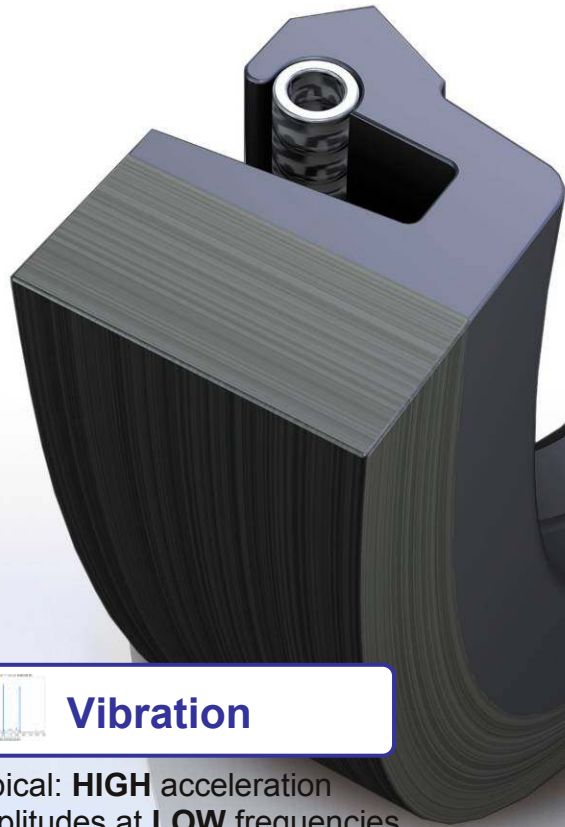
- Integration of FDS products in new applications
- Product upgrading



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Ambient Energy Sources



Vibration

- Typical: **HIGH** acceleration amplitudes at **LOW** frequencies
- Frequencies and amplitudes depending on application
- Industrial solutions available
- Harvested Power: μW ...mW

Shaft rotation

- Typical: Is the primary energy source
- Adaptable to different energy requirements
- Harvested Power: up to several W



Temperature

- Typical: **SYSTEM** Temperature vs. **AMBIENT** Temperature
- Constant ΔT necessary
- Thermal equilibrium dependent to environment temperature
- Harvested Power: up to several 100 mW

Stray field

- Typical: Sealing systems are often interstratified by electro magnetic stray fields (e.g. E-Motor)
- Use stray field for RF-induced Energy Harvesting
- Frequencies and amplitudes depending on application
- Harvested Power: up to several 100 mW

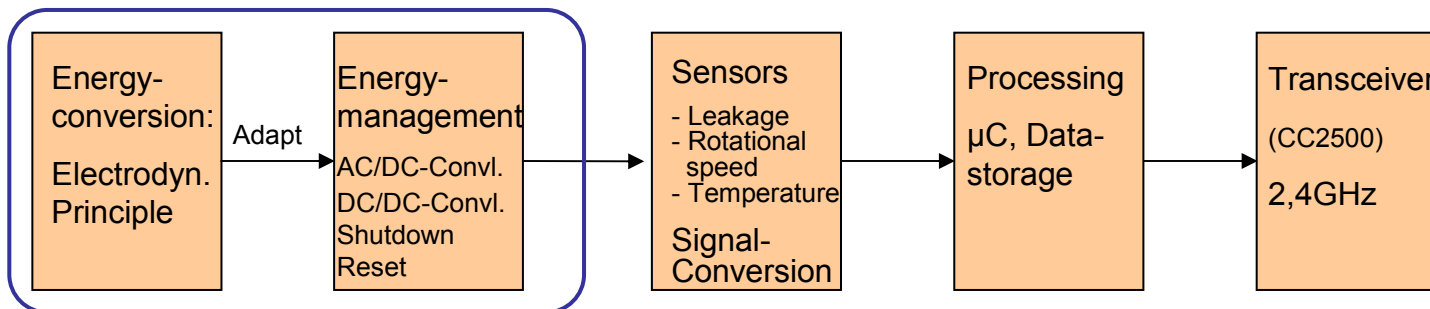
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Application Example

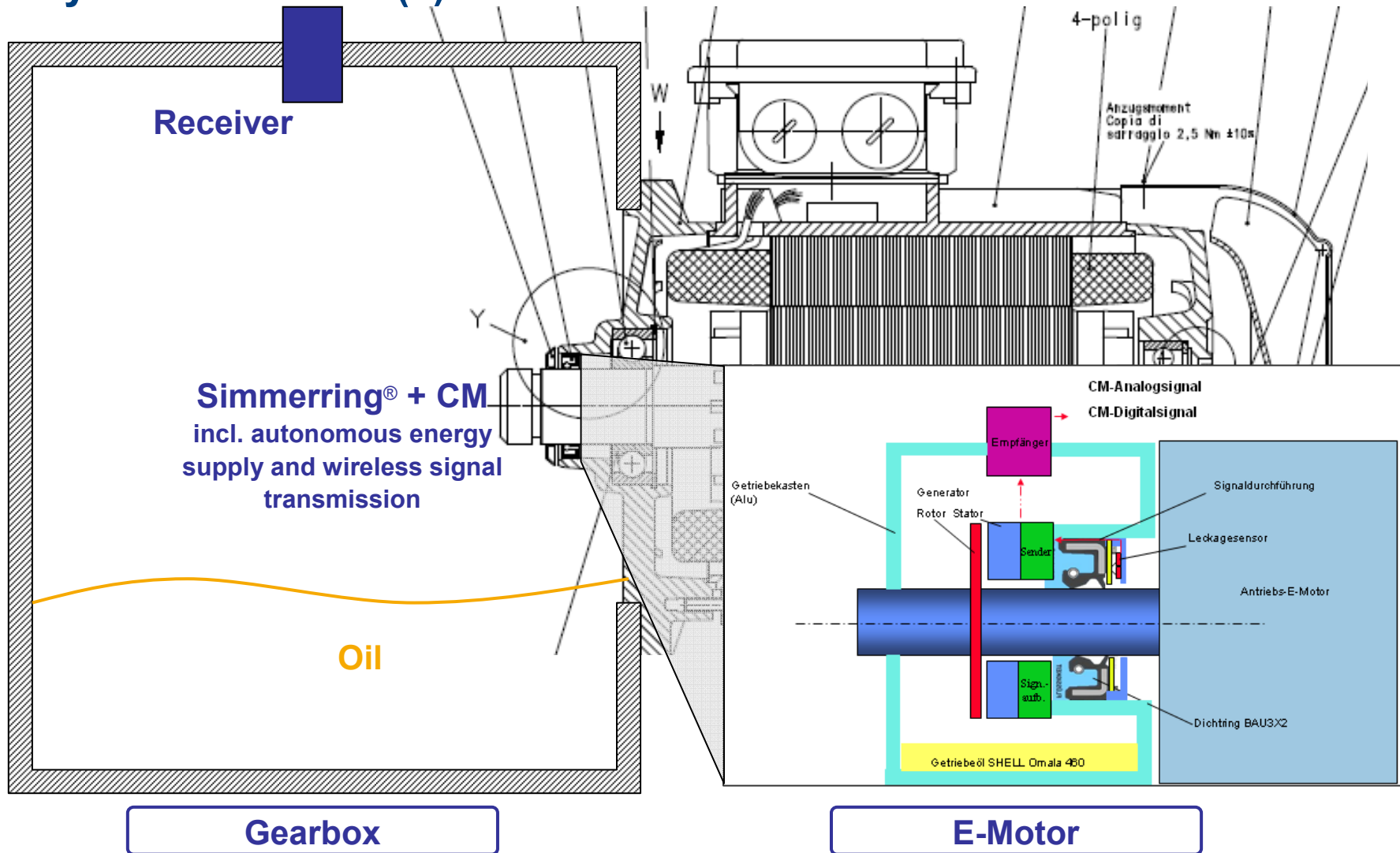
System Overview (1)

- Application: E-Motor with Simmerring® + Condition Monitoring, autonomous energy supply and wireless signal transmission
- Project goal: Case study for autarkic SensorSeal
- Project results: Demonstrator of Motor-Gearbox-Unit for industrial drive applications
- Cooperation: Lenze GmbH, Fraunhofer ENAS, Fraunhofer IZM
- Electronic Components:



Source: own representation

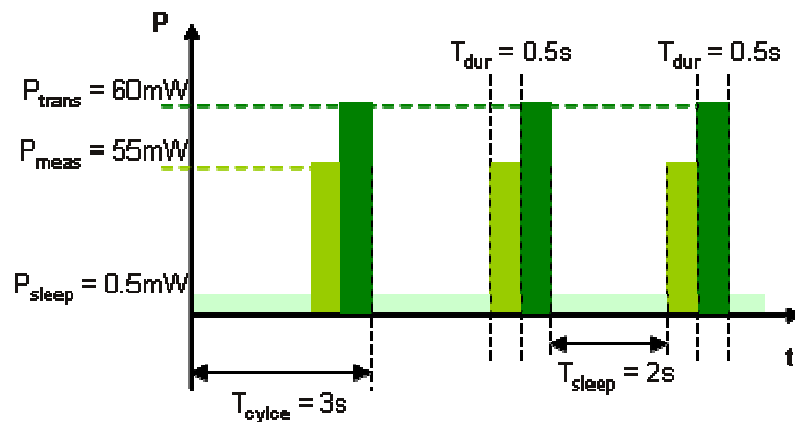
Application Example System Overview (2)



Application Example Requirements

Power consumption

- 60mW peak, 20mW average



Source: own representation

Power sources

- Temperature difference: 20...45K
- Rotational speed: 1400...2500 rpm
- Stray field
- Approximation @ 6.8cm^3 :
 - Rotation (Claw-pole): 2,7 W
 - Stray field: 0,68 W
 - Thermocouple: 33 mW
 - Vibration (el.magn.) : 10 mW

Simmerring® Dimensions

- Inner radius: $r_i = 16\text{ mm}$
- Outer radius: $r_a = 30\text{ mm}$
- Maximal axial space for generator: 10 mm

$$\left. \begin{array}{l} \\ \\ \end{array} \right\} V_{total} \sim 6.8\text{ cm}^3$$

Application Example

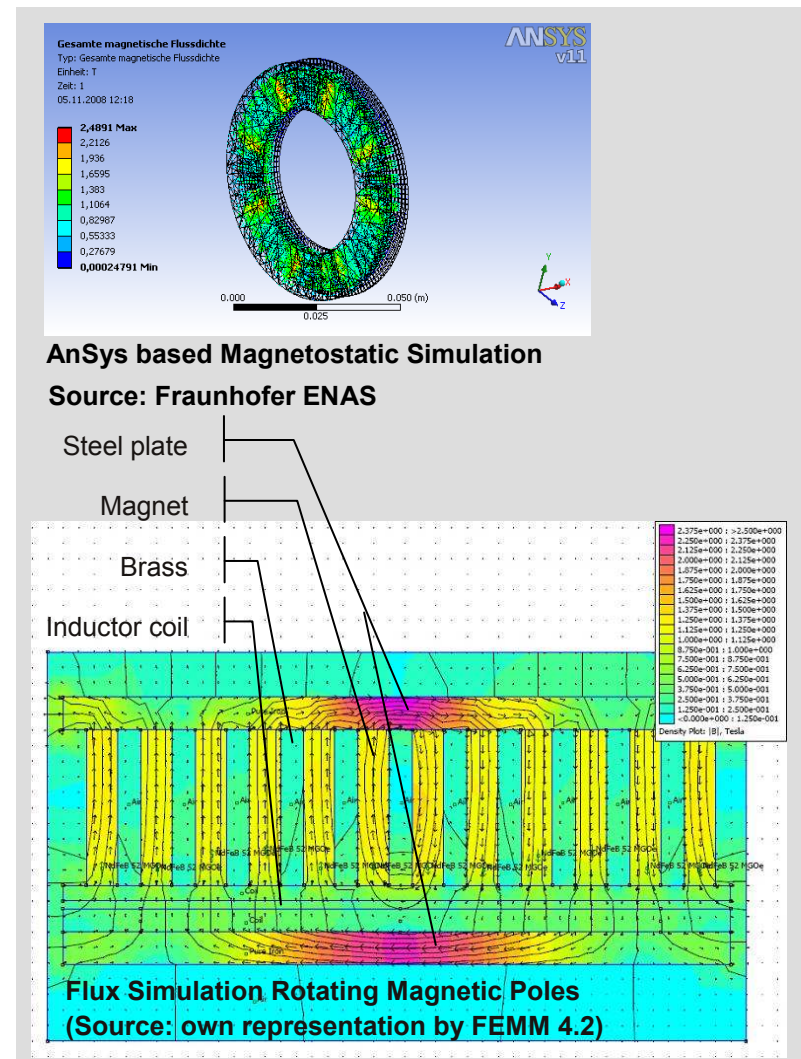
Generator design/ Simulation

Working Principle

- Rotating permanent magnets induce voltage in a static planar coil placed in air gap
- Height of voltage depending on rotational speed, number of windings, number of pole pairs

Expected Power

- P (B, dA/dt, N, $1/(R+w*L)$) ~100's of mW
- B (~ 0,177T) can be increased by
 - small air gaps e.g. 0,5mm
 - strong magnets e.g. NeFeB (NE038)
 - coil flux guide with good magnetic conductance e.g. Mu-Metal
- dA/dt can be increased by **increasing** number of **pole pairs** ~ 4 pole pairs @ 12 layers
- N can be **increased** by more **conductive layers** and higher number of **pole pairs** ~830
- R can be **decreased** by lower number of **pole pairs** and **conductive layers** ~100 Ohm
- L can be **decreased** by lower number of **conductive layers** ~0.125mH



Application Example

Generator design/ Calculation

Induced Voltage

$$U_a = -N \frac{d\Phi}{dt}$$

$$U_a = -N \frac{\Delta(B \cdot A)}{\Delta t}$$

with

$$w = 2 \cdot \pi \cdot p \cdot n$$

$$dA(t)/dt = w/p \cdot (r_a^2 - r_i^2)$$

and under assumption of $\Delta B = \text{const}$

$$U_a = N \cdot \Delta B \cdot 2 \cdot n \cdot \pi \cdot (r_a^2 - r_i^2)$$

Maximum Power in case of impedance matching

$$R_L = R_{gen} + X_{gen}$$

$$P_{max} = U_a^2 / 4 \cdot R_L$$

Design example:

- Output Voltage: 10V @ 1000 rpm
- Output Power: 245 mW

Legend:

r_a : outer radius generator

r_i : inner radius generator

p: Pole Pairs

n: rotational speed

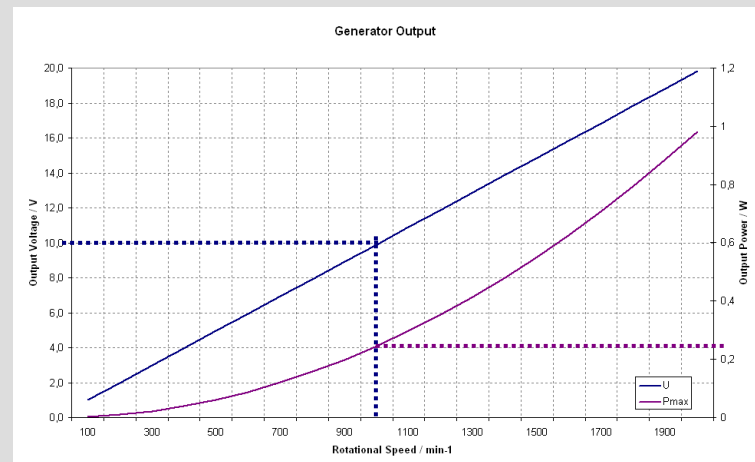
N: Windings

R_{gen} : Inner resistance generator

R_L : Load resistance

X_{gen} : Inner inductive resistance generator

ΔB : Magnetic flux
(depending on air gap size see Figure below)

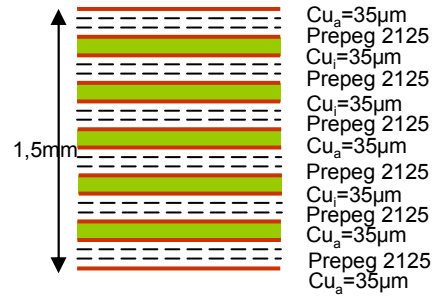


Source: own representation

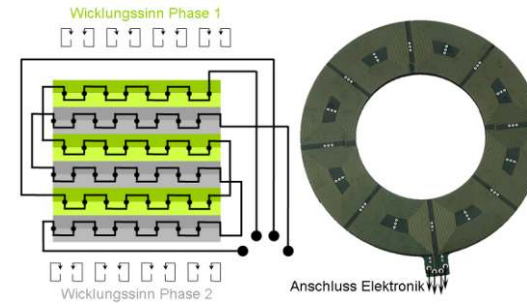
Application Example

Generator design/ Results

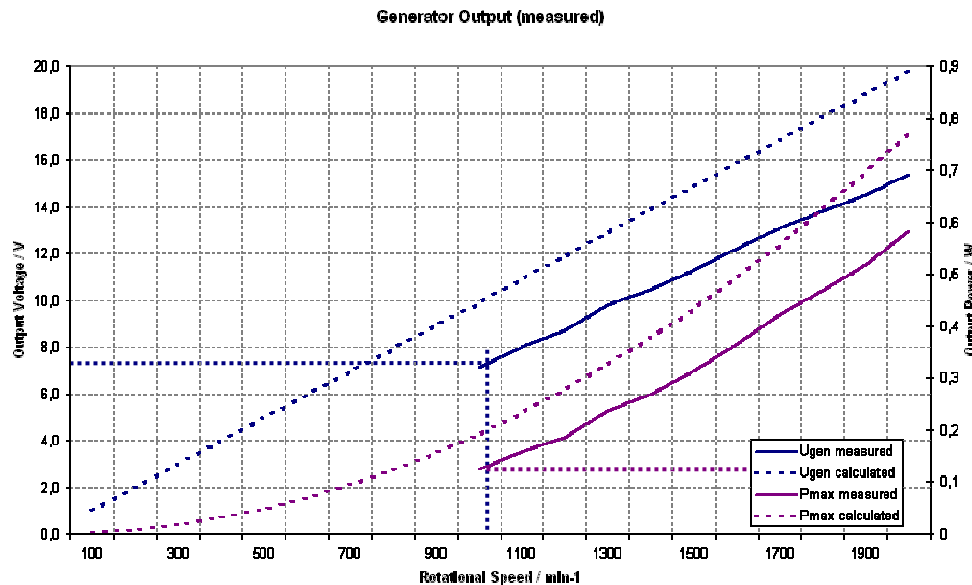
- Coil design
 - 12 conductive Layers
 - 4 pole Pairs
 - N = 830
 - Two-Phase-Design



Source: Fraunhofer ENAS



- Rotational speed dependent output voltage U_a



Source: own representation

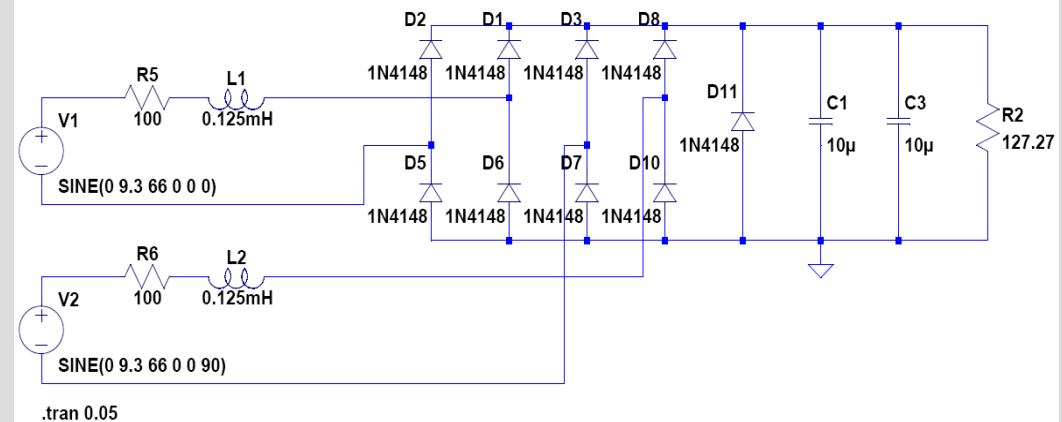
Generator results

- An output voltage of 7.1V can be achieved at 1000 rpm
 - The inner resistance of the generator is ~100 Ohm
 - An output power of 125 mW can be achieved at 1000 rpm (~ impedance matching)
 - Difference between simulation and measured results is ~28% (due to strong influence of air gaps and coil flux guide)
- Continuous Power Supply is possible
-> no additional energy storage is needed

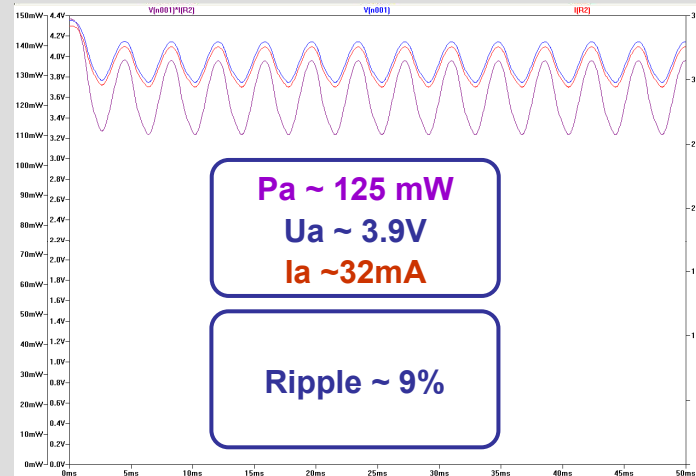
Application Example

Voltage scaling and conversion

- Due to high generator output voltages "standard" full-bridge rectifier can be used
- To minimize conversion losses use Schottky-Barrier-Diodes with low forward voltage
- Low ripple of supply voltage U_a
->2 phase/parallel
- $U_a > 3,3V @ 1000 \text{ rpm}$



LTSpice Simulation schematics (R5/R6 = Rgen; L1/L2= Lgen; R2= RL)

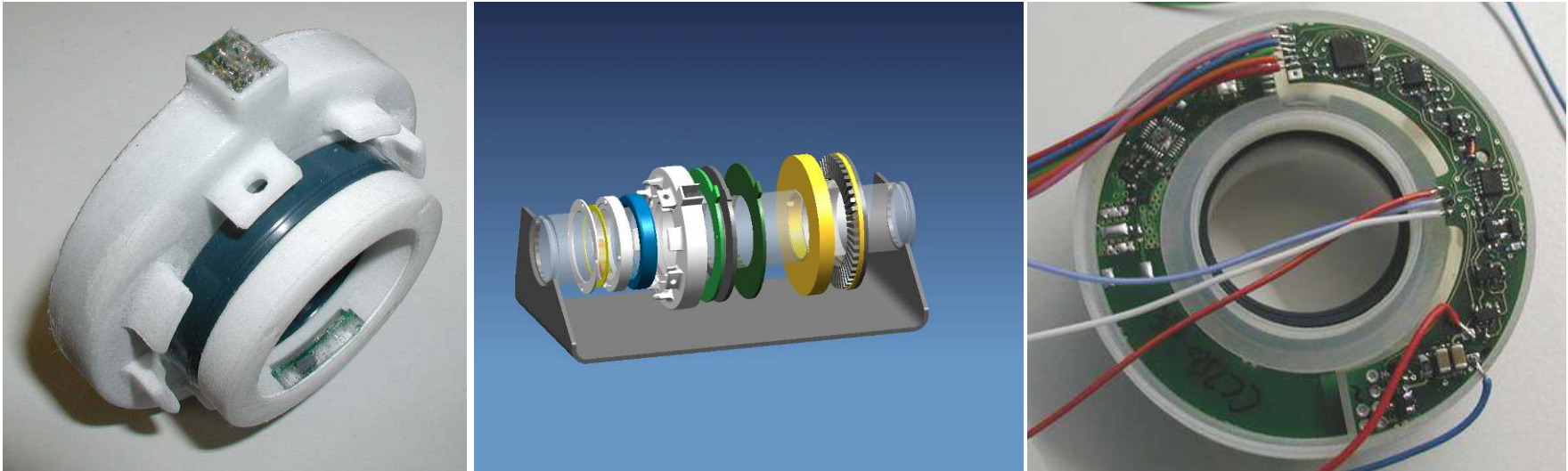


LTSpice Simulation results

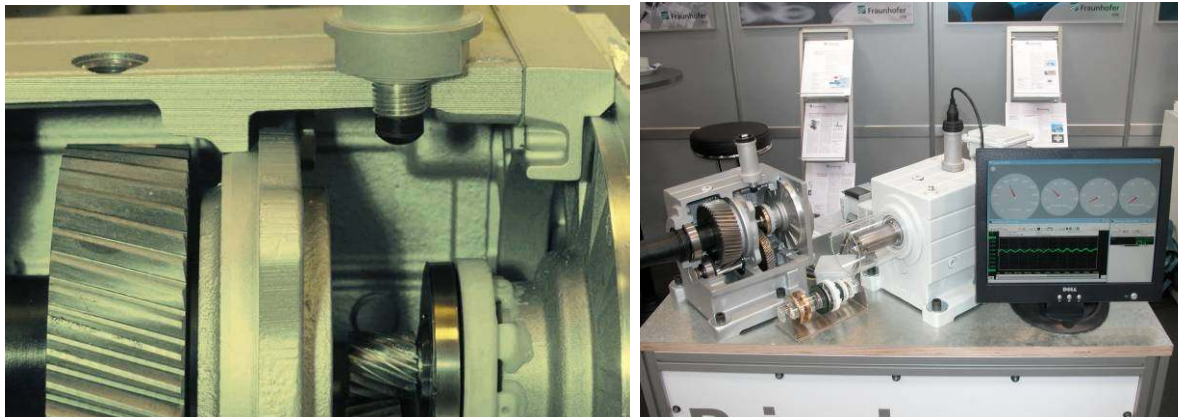
Source: own representation

Application Example Results

- Simmerring + CM (Autonomous and Wireless)



- Integration into Lenze E-Motor



Source:
own representation

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Summary

- Industrial application of Energy Harvesting Systems is possible even in harsh environments
- For intelligent Sealing solutions rotational energy is most promising source for “high” power Energy Harvesting
- Small Electro-dynamic generators ($\sim 7\text{cm}^3$) gain sufficient output power $\sim 125\text{ mW}$
 - Power density $18\text{mW}/\text{cm}^3$
- For more information visit booth of...
 - Simrit (Hall 19, B26)
 - Fraunhofer ENAS (Hall 6, H18)



Energy Harvesting approaches for intelligent Sealing Systems

Thank you for your attention!



Marcel SCHREINER

Freudenberg Dichtungs- und Schwingungstechnik
GmbH & Co KG
INNOVATIONCENTER
Mechatronics

Tel +49 (06201) 80 4221
marcel.schreiner@freudenberg-ds.com

