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Effect of variable mechanical resistance on electrodynamic alternator efficiency

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ABSTRACT

The rapidly growing energy market constantly discovers new alternatives for generating environmentally-friendly electricity from sustainable energy sources. An externally-heated traveling wave thermo acoustic Stirling heat engine is a leading candidate, operating using a variety of viable heat sources. Although this engine holds great promise for a low-cost and maintenance-free solution, its current reported efficiency still inhibits its market penetration, probably owing to the friction introduced by the single moving element – the linear alternator.

This research quantifies the main parameters affecting the complex thermal–acoustical–electrical system, clarifying the critical role of frictional losses. An analytical model has been developed, enabling examination of the influence of the critical physical parameters on the electro-acoustic conversion efficiency. A measurement method for precise determination of the mechanical friction constant has been developed, which enables measuring the friction at the engine's working frequency. A direct measurement of an engine's transfer impedance at room temperature enables to find the exact natural frequency before field operation, and calibrate external hardware accordingly. A detailed simulation using DeltaEC[™] indicates that the tight seal gap between the moving piston and its cylinder has a significant impact on the system's overall efficiency.

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1. Introduction

Efficient Thermo Acoustic Stirling heat Engines (TASE), allowing for reliable operation without moving parts or sliding seals, have recently stirred a revival of interest. These environmentallyfriendly, externally-heated engines may operate using a variety of viable heat sources, including natural gas, biofuels, open fire or solar radiation. Additionally, the lack of need for complex fabrication processes in the simple TASE structure makes it an excellent candidate for commercial solar electricity production. Nowadays, the rapidly growing solar-thermal market finds great promise in new methods for converting Concentrated Solar Power (CSP) into electricity.

The "traveling wave" thermo-acoustic engine employs the inherently reversible Stirling cycle, theoretically capable of attaining Carnot efficiency. A practical demonstration of a thermoacoustic engine has produced a thermal efficiency (heat to acoustic power) of 30% [1] at 725 °C, comparable to that of modern internal combustion engines [2] (25–40% heat to mechanical

power). Converting acoustic power into mechanical and/or electrical power is no small challenge, and forms the subject of this work. A commercial thermoacoustic system has produced over 17 kW of acoustic power [3] which was then used to liquefy natural gas (Methane liquefies at 115 K at atmospheric pressure) at a rate as high as 140 gpd. In 2004, a remarkable thermoacoustic engine, converting heat into electricity, was developed by Northrop Grumman Space and Technology group with Los Alamos National Laboratory under a NASA contract [4]. This engine produced 39 W of electrical power at 18% overall conversion efficiency (heat to electricity), where a pair of dual opposed linear alternators were driven by acoustic power [5]. Using Inconel 625 for the hot heat exchanger has allowed working temperatures as high as 650 °C which enabled the first implementation of a traveling wave thermoacoustic engine for efficient electricity production.

Higher power levels have been demonstrated in 2005 by Luo et al. [6], as the nonlinear dissipation losses were reduced in the acoustic resonator by employing a tapered resonance tube. In 2008 [7] more than 100 W electrical output power were produced through proper coupling between the linear alternator and the thermoacoustic engine, and in 2011 [8] the electrical output power was further increased to as much as 481 W with thermal to







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Nomenclature

$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	Α	cross section area, m ²	Z_m^e, Z_a^e	electrical equivalent of mechanical, acoustic impedance,
	B	magnetic field, T	-	Ω
$ \begin{array}{cccc} Compliance, m //ra \\ c capacitance, F \\ F \\ force, N \\ f \\ frequency, Hz \\ L_1 total (real), oscillatory part (complex), of electrical current, A \\ effective, N/m \\ L \\ inertance, kg/m^4 \\ L_e \\ electrical inductance, H \\ L_e \\ electrical inductance, H \\ L_e \\ electrical constant (mechanical), gas spring, \\ m \\ mass, kg \\ p, p_m, p_t total, mean part (real), oscillatory part (complex) of \\ mechanical damping, N-s/m \\ R_r & R_e \\ electrical resistance (internal, external load), \Omega \\ R_r & R_e \\ r \\ acoustic free resistance (internal, external load), \Omega \\ R_r & nechanical damping, N-s/m \\ R_r \\ r \\ acoustic flow resistor, N-s-m^3 \\ F \\ r \\ r$	(BI)	alternator constant, N/A	Z_c	transfer impedance, A-s/m
$ \begin{array}{cccc} c & capacitance, r & N^{-S}m \\ f & force, N & f & cplc_v adiabatic ratio \\ f & frequency, Hz & f & cplc_v adiabatic ratio \\ f & frequency, Hz & f & f & cplc_v adiabatic ratio \\ f & cplc_v adiabatic ratio \\ f & f & cplc_v adiabatic \\ f & f & cplc_v adiabatic ratio \\ f & f & cplc_v adiabatic \\ f & f & cplc_v adiabati$	C	compliance, m ³ /Pa	Z_m , $Z_{m,a}$	mechanical impedance (total, mechanical-acoustical),
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Ce	capacitance, F		N-s/m
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	F	force, N	γ	c_p/c_v adiabatic ratio
$ \begin{array}{c} 1, 1_{1} total (real), oscillatory part (complex), of electrical current, A construction interval, A cons$	J	frequency, Hz	η	efficiency
	I, I ₁	total (real), oscillatory part (complex), of electrical	ζ	displacement, m
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$,	current, A	ρ , ρ_m , ρ	total, mean part (real), oscillatory part (complex) of
K. K. Kges-spring enderstandConstant (internation), gas spring, enderstand), gas spring, enderstand), gas spring, enderstand), gas spring, (m_1, m_2, m_1) , place between p_1 of Δp_1 and D_1 angular frequency 1/sLinertance, kg/m ⁴ Leelectrical inductance, H m mass, kgSupplementary notation \Re { imaginary partLinertance, kg/m ⁴ LeSupplementary notation \Re { imaginary partmmass, kg p, p_m, p_1 total, mean part (real), oscillatory part (complex) of temperature, KSupplementary notation \Re { imaginary partrpower, W ressure Pa, (N/m ²)imaginary part $(1 < \sqrt{-1})$ $(1 < \sqrt{-1})$ absolute value, Norm $(1 < \sqrt{-1})$ rpressure Pa, (N/m ²)imaginary part $(1 < \sqrt{-1})$ $(1 < \sqrt{-1})$ absolute value, Norm $(1 < \sqrt{-1})$ rpressure Pa, (N/m ²)imaginary part $(1 < \sqrt{-1})$ $(1 < \sqrt{-1})$ absolute value, Norm $(1 < \sqrt{-1})$ rpressure Pa, (N/m ²)imaginary part $(1 < \sqrt{-1})$ $(1 < \sqrt{-1})$ absolute value, Norm $(1 < \sqrt{-1})$ rpressure Pa, (N/m ²)imaginary part $(1 < \sqrt{-1})$ rrrstationrrstationrrstationrrstationrr <td></td> <td>acoustic intensity, w/m⁻</td> <td>1 1</td> <td>density kg/m²</td>		acoustic intensity, w/m ⁻	1 1	density kg/m ²
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	к, к _{gas-s}	effective, N/m	$\varphi_{p_1,U_1},\varphi_2$ ω	angular frequency $1/s$
$ \begin{array}{cccc} L_e & \mbox{electrical inductance, H} & \mbox{Supplementary notation} \\ l & \mbox{characteristic or effective length, m} & \mbox{$\Re($)$} & \mbox{relation} \\ relation m & \mbox{mass, \aleph} & \mbox{$\Re($)$} & \mbox{relation} \\ m & \mbox{mass, \aleph} & \mbox{$\Re($)$} & \mbox{relation} \\ m & \mbox{mass, \aleph} & \mbox{$\Re($)$} & \mbox{relation} \\ pressure Pa, (N/m^2) & \mbox{$(1]$} & \mbox{absolute value, Norm} \\ pressure Pa, (N/m^2) & \mbox{$(1]$} & \mbox{absolute value, Norm} \\ pressure Pa, (N/m^2) & \mbox{$(1]$} & \mbox{absolute value, Norm} \\ pressure Pa, (N/m^2) & \mbox{$(1]$} & \mbox{absolute value, Norm} \\ pressure Pa, (N/m^2) & \mbox{$(1]$} & \mbox{absolute value, Norm} \\ pressure Pa, (N/m^2) & \mbox{$(1]$} & \mbox{$(1]$} & \mbox{absolute value, Norm} \\ pressure Pa, (N/m^2) & \mbox{$(1]$} & $$	L	inertance, kg/m ⁴		
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Le	electrical inductance, H	Sunnlem	entary notation
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	1	characteristic or effective length, m	R{}	real part
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	т	mass, kg	3 {}	imaginary part
$ \begin{array}{cccc} & \mbox{pressure Pa, (N/m^2)} & () & \mbox{complex conjugate} \\ \vec{r} & \mbox{Power, W} & i & \sqrt{-1} \\ \hline \mbox{R, $R_e, R_t electrical resistance (internal, external load), Ω & () & \mbox{time average} \\ \hline \mbox{R_m} & \mbox{mechanical damping, $N-s/m} & \mbox{A} & \mbox{difference} \\ \hline \mbox{R_m} & \mbox{acoustic flow resistor, $N-s-m^3$ \\ \hline \mbox{r} & \mbox{space vector, m} \\ \hline \mbox{r} & \mbox{space vector, m} \\ \hline \mbox{r} & \mbox{space vector, m} \\ \hline \mbox{r} & \mbox{tremperature, K & \\ \hline \mbox{t} & \mbox{time, s & \\ \hline \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \\ \hline \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \\ \hline \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \\ \hline \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \\ \hline \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \\ \hline \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \\ \hline \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \\ \hline \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \\ \hline \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \\ \hline \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \\ \hline \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \\ \hline \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \mbox{t} & \\ \hline \mbox{t} & \\ \hline \mbox{t} & t$	p, p _m , p ₁	total, mean part (real), oscillatory part (complex) of	II II	absolute value. Norm
\vec{r} Power, W i $\sqrt{-1}$ V_{T} R, R_e, R_L electrical resistance (internal, external load), Ω $\langle\rangle$ time average R_m mechanical damping, N-s/m Δ difference R_m acoustic flow resistor, N-s-m ³ Δ difference \vec{r} space vector, m Δ difference T, T_m, T_I total, mean part (real), oscillatory part (complex) of temperature, K ALT alternator t time, s ALT alternator U, U_1 total (real), oscillatory part (complex), of volumetric flow rate, m ³ /s CS compression space u, u_1 total (real), oscillatory part (complex), x component of velocity, m/s CS compression space V volume, m ³ e electronotive force V_{EMF}, V_I, V_{int} voltage, V ext external χ_a, Z_{ALT} acoustic impedance (total, acoustic representation of 		pressure Pa, (N/m ²)	$()^*$	complex conjugate
R, R_e, R_Lelectrical resistance (internal, external load), Ω \langle time averageR_mmechanical damping, N-s/m Δ differenceR_racoustic flow resistor, N-s-m ³ Subscript \vec{r} space vector, mSubscript \vec{r} total, mean part (real), oscillatory part (complex) of temperature, K AE acoustic-electrical t time, s ALT alternator U, U_1 total (real), oscillatory part (complex), of volumetric flow rate, m ³ /s C C U, u_1 total (real), oscillatory part (complex), x component of velocity, m/s e electronic velocity, m/s V volume, m ³ $external$ EMF electroic V_{EMF}, V_I, V_{int} voltage, V EA electroic $external$ χ axial coordinate, m m mechanical m m χ axial coordinate, m m mechanical m m χ $Z_e, ZALT$ acoustic impedance (total, acoustic representation of alternator impedance), N-s/m ⁵ TA thermoacoustic $Z_{e,int.}$ $Z_{e,total}$ electrical (internal, external, total) impedance, 1 TA thermoacoustic	r	Power, W	i	$\sqrt{-1}$
$ \begin{array}{cccc} R_m & \operatorname{mechanical damping, N-s/m} & & & & & & & & & & & & & & & & & & &$	R, R_e, R_L	electrical resistance (internal, external load), Ω	$\langle \rangle$	time average
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	R_m	mechanical damping, N-s/m	Å	difference
$ \vec{r} \qquad \text{space vector, m} \\ \vec{r}, T_m, T_1 \ \text{total, mean part (real), oscillatory part (complex) of temperature, K \\ \vec{r} \qquad \text{time, s} \\ \vec{r}, U_1 \ \text{total (real), oscillatory part (complex), of volumetric flow rate, m^3/s \\ \vec{r}, u_1 \ \text{total (real), oscillatory part (complex), x component of velocity, m/s \\ \vec{r}, velocity, m/s \\ \vec{v} \qquad volume, m^3 \\ \vec{v} \qquad \text{volume, m}^3 \\ \vec{v} \qquad \text{volocity vector, m/s \\ \vec{x} \qquad axial coordinate, m \\ \vec{y}, z \ \text{transverse coordinate, m} \\ \vec{y}, z \ transverse coordinate, m \\ \vec{y}, z \ transverse \ transverse coordinate, m \\ \vec{y}, z \ transverse \ transve$	R_r	acoustic flow resistor, N-s-m ³		
T, T_m , T_1 total, mean part (real), oscillatory part (complex) of temperature, KAE acoustic-electrical ALTttime, sALTalternatorttime, sacousticcU, U1total (real), oscillatory part (complex), of volumetric flow rate, m³/sacousticcu, u1total (real), oscillatory part (complex), x component of velocity, m/sCScompression spaceVvolume, m³eelectromotive forceVvolume, m³eelectricVvolume, m³extexternalVvelocity vector, m/sintinternalxaxial coordinate, mmmechanicaly, ztransverse coordinate, mm, amechano-acousticz _{e,int} , Z _{e,ext} , Z _{e,total} electrical (internal, external, total) impedance, Ω TAthermacousticQ1oscillatory variableinternal	r	space vector, m	Subscript	
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	T, T _m , T ₁	total, mean part (real), oscillatory part (complex) of	AE	acoustic-electrical
ttime, saacoustic U, U_1 total (real), oscillatory part (complex), of volumetric flow rate, m³/saacoustic u, u_1 total (real), oscillatory part (complex), x component of velocity, m/saacoustic V volume, m³ ext electromotive force V volume, m³ ext external V_{EMF}, V_1, V_{int} voltage, V EA electro-acoustic \vec{v} velocity vector, m/sintinternal x axial coordinate, m m mechanical y, z transverse coordinate, m m mechanical y, z transverse coordinate, m m, a mechano-acoustic Z_a, Z_{ALT} acoustic impedance (total, acoustic representation of alternator impedance), N-s/m⁵ TA thermoacoustic $Z_{e,inb}, Z_{e,exb}, Z_{e,total}$ electrical (internal, external, total) impedance, 1 $TASE$ Thermo Acoustic Stirling Engine		temperature, K	ALT	alternator
U, U_1 total (real), oscillatory part (complex), of volumetric flow rate, m³/s c characteristic u, u_1 total (real), oscillatory part (complex), x component of velocity, m/s CS compression space V volume, m³ e electromotive force V volume, m³ ext external V_{EMF}, V_1, V_{int} voltage, V EA electro-acoustic \vec{v} velocity vector, m/sintinternal x axial coordinate, m m mechanical y, z transverse coordinate, m m mechanical y, z transverse coordinate, m m, a mechano-acoustic Z_a, Z_{ALT} acoustic impedance (total, acoustic representation of alternator impedance), N-s/m⁵ TA thermoacoustic $Z_{e,inb}, Z_{e,exb}, Z_{e,total}$ electrical (internal, external, total) impedance, 1 $TASE$ Thermo Acoustic Stirling Engine 1	t	time, s	а	acoustic
flow rate, m³/sCScompression space u, u_1 total (real), oscillatory part (complex), x component of velocity, m/s CS compression space V volume, m³electromotive force V volume, m³extelectric V_{EMF}, V_1, V_{int} voltage, V EA electro-acoustic \vec{v} velocity vector, m/sintinternal x axial coordinate, m m mechanical y, z transverse coordinate, m m mechanical z_a, Z_{ALT} acoustic impedance (total, acoustic representation of alternator impedance), N-s/m⁵ m, a mechano-acoustic $Z_{e,inb}, Z_{e,exb}, Z_{e,total}$ electrical (internal, external, total) impedance, 1 TA thermoacoustic $TASE$ Thermo Acoustic Stirling Engine 1 oscillatory variable	U, U ₁	total (real), oscillatory part (complex), of volumetric	с	characteristic
u, u_1 total (real), oscillatory part (complex), x component of velocity, m/sEMFelectromotive force eVvolume, m^3 extexternal V_{EMF}, V_1, V_{int} voltage, VEAelectro-acoustic \vec{v} velocity vector, m/sintinternalxaxial coordinate, mmmechanicaly, ztransverse coordinate, mmmechanicalZa, ZALTacoustic impedance (total, acoustic representation of alternator impedance), N-s/m ⁵ mmechano-acousticZe,inbZe,exbZe,totalelectrical (internal, external, total) impedance, 1TAthermoacousticTASEThermo Acoustic Stirling Engine 1oscillatory variable		flow rate, m ³ /s	CS	compression space
$ \begin{array}{cccc} velocity, m/s & e & electric \\ V & volume, m^3 & ext & external \\ V_{EMF}, V_1, V_{int} & voltage, V & EA & electro-acoustic \\ \vec{v} & velocity vector, m/s & int & internal \\ x & axial coordinate, m & m & mechanical \\ y, z & transverse coordinate, m & m & mechanical \\ z_a, Z_{ALT} & acoustic impedance (total, acoustic representation of alternator impedance), N-s/m^5 & TA & thermoacoustic \\ Z_{e,inb} & Z_{e,exb} & Z_{e,total} & electrical (internal, external, total) impedance, 1 & oscillatory variable \\ \end{array} $	<i>u</i> , <i>u</i> ₁	total (real), oscillatory part (complex), x component of	EMF	electromotive force
V volume, m ³ extexternal V_{EMF}, V_1, V_{int} voltage, V EA electro-acoustic \vec{v} velocity vector, m/sintinternal x axial coordinate, m m mechanical y, z transverse coordinate, m m mechanical Z_a, Z_{ALT} acoustic impedance (total, acoustic representation of alternator impedance), N-s/m ⁵ m, a mechano-acoustic $Z_{e,inb}, Z_{e,exb}, Z_{e,total}$ electrical (internal, external, total) impedance, 1 TA thermoacoustic $TASE$ Thermo Acoustic Stirling Engine 1 oscillatory variable		velocity, m/s	е	electric
$ \begin{array}{cccc} V_{EMF}, V_1, V_{int} \text{voltage}, V & EA & \text{electro-acoustic} \\ \vec{v} & \text{velocity vector, m/s} & \text{int} & \text{internal} \\ x & \text{axial coordinate, m} & m & \text{mechanical} \\ y, z & \text{transverse coordinate, m} & n & \text{mechanical} \\ z_a, Z_{ALT} & \text{acoustic impedance (total, acoustic representation of} & alternator impedance), N-s/m^5 & TA & thermoacoustic \\ Z_{e,inb}, Z_{e,exb}, Z_{e,total} & \text{electrical (internal, external, total) impedance,} & TA & thermoacoustic \\ \Omega & & 0 & 0 & 0 & 0 \\ \end{array} $	V	volume, m ³	ext	external
VVelocity vector, m/sintinternalxaxial coordinate, mmmechanicaly, ztransverse coordinate, mmmechanical Z_a, Z_{ALT} acoustic impedance (total, acoustic representation of alternator impedance), N-s/m5m, amechano-acoustic $Z_{e,inb}, Z_{e,exb}, Z_{e,total}$ electrical (internal, external, total) impedance, Ω TAthermoacousticTASEThermo Acoustic Stirling Engine 1oscillatory variable	V_{EMF} , V_1 ,	V _{int} voltage, V	EA	electro-acoustic
x axial coordinate, m m mechanical y, z transverse coordinate, m m, a mechano-acoustic Z_a, Z_{ALT} acoustic impedance (total, acoustic representation of alternator impedance), N-s/m ⁵ m, a mechano-acoustic $Z_{e,inb}, Z_{e,exb}, Z_{e,total}$ electrical (internal, external, total) impedance, Ω TA thermoacoustic TA thermoacousticTASEThermo Acoustic Stirling Engine 1	V	velocity vector, m/s	int	internal
z_a z_{ac} <	<i>x</i>	dxidi coordinate, ili	т	mechanical
$\begin{array}{c} Z_{a}, Z_{ALT} \\ alternator impedance), N-s/m^5 \\ Z_{e,intb}, Z_{e,cotal} \\ \Omega \end{array} \begin{array}{c} \text{regenerator} \\ \text{TA} \\ \Omega \\ \end{array} \begin{array}{c} \text{regenerator} \\ \text{TA} \\ \text{TASE} \\ 1 \\ \end{array} \begin{array}{c} \text{regenerator} \\ \text{TASE} \\ \text{Thermo Acoustic Stirling Engine} \\ \text{oscillatory variable} \end{array}$	y, 2 7 7	acoustic impedance (total acoustic representation of	т, а	mechano-acoustic
$\begin{array}{c} TA \\ Z_{e,int} & Z_{e,cotal} & \text{electrical (internal, external, total) impedance,} \\ \Omega \end{array} \begin{array}{c} TA \\ TASE \\ 1 \end{array} \begin{array}{c} \text{thermoacoustic} \\ TASE \\ 1 \end{array}$	∠ _a , ∠ _{ALT}	acoustic impedance (total, acoustic representation of alternator impedance) N_s/m^5	REG	regenerator
Ω TASE Thermo Acoustic Stirling Engine oscillatory variable	7 . 7	7 electrical (internal external total) impedance	TA	thermoacoustic
1 oscillatory variable	∠ e,ınt, ∠ e,e	Ω	TASE	Thermo Acoustic Stirling Engine
		26	1	oscillatory variable

electricity efficiency of 12.65% at 650 °C, using 3.5 MPa pressurized helium at typical engine working conditions.

Additional recent projects include the work done at the Energy Research Center of the Netherlands (ECN) by Tijani and co-workers [9–11]; the FP7 cooperative project on thermoacoustic technology for energy applications led by Spoelstra, Thermeau, Jaworski and de Blok [12–14]; the power converter built by Telesz at Georgia Institute of Technology [15]; the large-scale-engine research performed by Qiu et al. at the Institute of Refrigeration and Cryogenics, Zhejiang University, Hangzhou, China [16]; the investigation of low cost regenerator materials conducted by Yu, Jaworski and Abduljalil at the School of Mechanical, Aerospace and Civil Engineering, University of Manchester, England [17,18]; and the Score-Stove™ project aiming to generate electricity in developing countries using thermo-acoustics powered by burning wood. This project initiated a broad collaboration between the University of Nottingham, University of Manchester, Queen Mary University of London (QMUL), Imperial College London and Los Alamos National Laboratory (LANL) [19-23]; Recently, a solar-operated thermoacoustic Stirling engine has been reported for the first time to produce as much as 200 W of electrical power with overall efficiency of 12.7% (heat to electricity) at 750 °C [24]. The additional option of heating the engine with solar-thermal energy has led to

a compromise of the performance of this prototype compared to earlier versions [8].

Despite its conceptual simplicity and high reliability, nowadays further efficiency improvements are necessary for a complete TASE-based system to gain a market share. Other well-established heat-to-electricity conversion systems have been around for a long time, and competing with them, mainly for efficiency, represents an important challenge for the TASE system.

The main objective of this research has been to provide a qualitative understanding as well as quantitative analysis of the key parameters affecting the complex thermal–acoustical–electrical system. A fairly involved trade-off exists between different parameters affecting the performance of the system. In particular, we address the effect of mechanical friction, known to have a deleterious impact on the system performance. To better understand this effect, an analytical model is developed in this paper. Its results will be compared to a detailed thermoacoustic simulation using DeltaECTM in a separate paper. An alternative method of measurement for precise determination of the mechanical friction constant was developed and is described.

Section 2 gives a short background of thermo-acoustic-electrical transduction. An analytical model of the involved processes is presented in Section 3. Section 4 describes the experimental setup

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