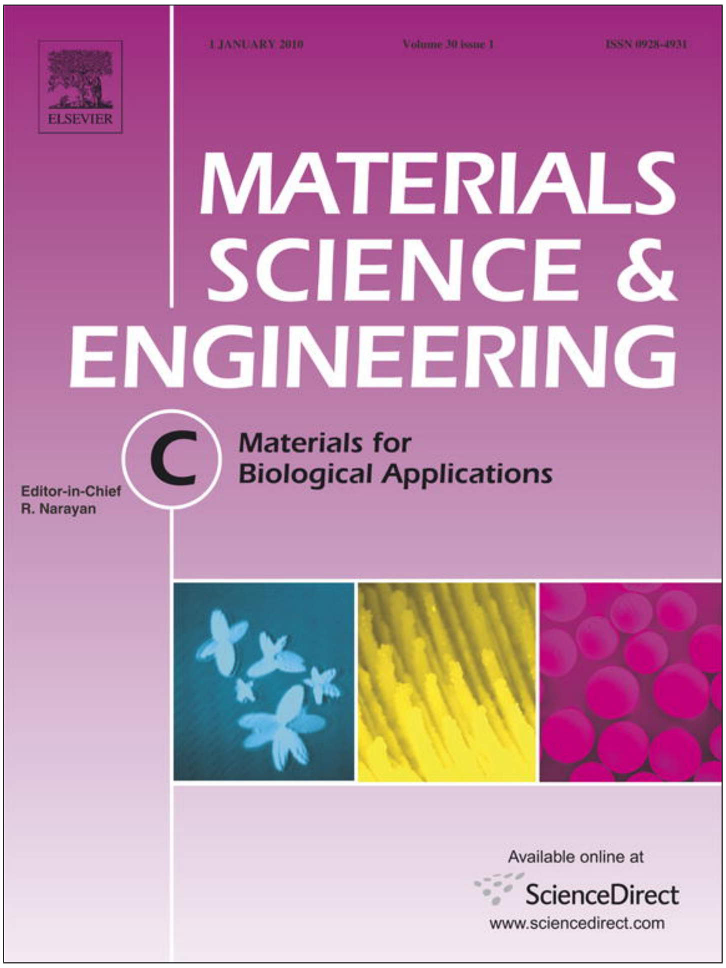
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Implementing DEA to create a novel type of compressor

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ABSTRACT

Presenting proper configuration for the context-aware compressor, a novel type of this device based on Dielectric Elastomer Actuators was designed and modeled by computer. The study was aimed at evaluating the concept potentials to operate in gas turbine engines according to an attempt to raise these engines up to context-aware systems. The study encompasses introducing a methodology to model the concept in addition to indicating its potentials. The modeling results indicated that low energy consumption and context-awareness potentially are two major characteristics of the compressor.

1. Introduction

Today many reasons are available for comprehensive change of conventional energy generation and consumption methods. Global warming, high price of fossil fuels and geopolitical problems linked to them in addition to limitations of their mining are the most important factors to boost researches into optimal ways to consume and generate energy.

Attracting many attentions, reducing energy consumption of available devices is one of the most effective methods. This work needs fewer changes in infrastructures and will be able to satisfy requirements in mid and long terms with minimum cost. However, such a development should not increase complexity of systems; in fact, more complicated systems can potentially raise the cost and reduce the tendency to use them.

Most of ways currently available to adapt conventional power systems to today demands dedicate the power to requirements. To reduce emission, noise and other harmful factors, the power suffers maximum losses.

However, heightening performance of power systems is a conventional and also effective method which is capable of improving both the fuel efficiency and the power. The performance of power and propulsion systems has always measured in different conditions encompassing environmental elements and users demands. As a result, many optimizations have been carried out toward improving adaptation ability to these factors. However, the author believes a different observation to the problem is necessary for creating the capability of real adaptation for them.

In the computer science, adaptation ability to user demands and environmental elements is briefly named "Context-Awareness" [1]. Attempting to apply this characteristic, environmental changes and user attitudes have been integrated into computer systems design process [2]. This fact encouraged the author to study of applying context-awareness on gas turbine engines, which needs a particular observation to effective factors.

This work urged extending free access to all key components in order to enhance the capability of adaptation to environmental elements and user demands. Creating such a capability needs essential changes in the power transmission from a turbine to the compressor and its stages operations [3].

Yet, these changes increase the complexity of the system and do not satisfy the aims. Therefore, the author turned attention to designing a novel compressor inherently compatible with context-awareness. Such a compressor should also be suitable for the particular power transmission method considered for a context-aware gas turbine in which free and individual access to the components would be available.

The outcome is an original conceptual compressor designed by Dielectric Elastomer Actuators (DEAs). The compressor can potentially

Abbreviations: AC, Alternating Current; DEA, Dielectric Elastomer Actuators; E, Applied Electric Field; EAP, Electro Active Polymers; IC, Integrated Circuits; RC, The time required to charge the capacitor, through the resistor, to 63.2 (≈63) percent of full charge, or to discharge it to 36.8 (≈37) percent of its initial voltage, in a circuit formed by a resistor and a capacitor.

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Nomenclature

A	Area
d	Dielectric constant relative to vacuum permittivity
D	Diameter
F	Force
f	Frequency
I_m	Current
L	Length
m	Air mass flow
N	Number
P	Pressure
T	Temperature
t	Thickness
V	Volume
V_m	Voltage
W	Power
w	Width
α	Extension ratio
η_∞	Polytropic efficiency
P	Air density

Units

A	Ampere
gr	gram
Hz	Hertz
K	Kelvin
kg	Kilogram
kJ	Kilo Joel
kN	Kilo Newton
kV	Kilovolt
kW	Kilowatt
m	Meter
mm	Millimeter
MPa	Mega Pascal
MV	Megavolt
s	Second
V	Volt
µm	Micrometer

Constants

c_p	Specific heat of air at constant pressure = 1.005 kJ kg/K
d_0	Vacuum permittivity = 8.854×10^{-12} Farad/m
g	Gravity Acceleration = 9.82 m/s^2
R	Gases Constant for Air = 0.287 kN m/kg K
γ	Ratio of Specific heats of Air = 1.4
π	3.14159

influence the technology of gas turbine engines and its effect on gas turbines may be similar to the transistor and the IC effects on electronic devices in early in the 1970s.

DEAs are one of the branches of Electro Active Polymers (EAPs), which encompass two major categories:

1. Ionic EAP (activated by an electrically-induced transport of ions or molecules)
2. Electronic EAP (activated by an external electric field and by Coulomb forces)

DEAs are considered a subcategory of the second type [4,5].

In fact, the date of the studies on polymer base actuators back to early in the 1950s by Kuhn and Katchalsky [6]. Nevertheless, most of them have been formed in the 1980s. EAPs have attracted attention for the applications for which other technologies are unsuitable or too expensive. Accordingly, in this study it shows the superior potentials to satisfy the aims when it causes energy consumption of a DEA compressor to be considerably less than a conventional one.

This paper explains the principles of this novel conceptual compressor beside the methods for its designing and modeling. A sample design is also presented to show its potentials.

2. Principles and structure

The concept consists of the several thin tubes that suck the air into a vessel. As a result, two main sections form the basic structure of the compressor (Fig. 1):

1. Cells
2. Vessel

Each cell consists of the several rings. The rings are made of DEA surrounding an elastomeric tube whose end is attached to the vessel (Fig. 2). Orderly expansion and contraction of these rings creates a gullet like movement by moving a knot from the tip to the root of the cells (Fig. 3). Such a movement inflates the vessel that would be depleted when its internal pressure reached a desirable value. Yet, to generate a steady flow, inflating and depleting processes should be carried out by high frequencies.

According to gases behavior in low density, closely given by the following equation:

$$PV = mRT$$

in a constant volume process by increasing mass, temperature and pressure increase. This fact can clearly be seen during inflating a bicycle tires.

The cells in the concept (Fig. 1) carry out the inflating procedure. DEAs in the rings (Fig. 4) expand when an adequate electric field is applied. In a normal situation, each ring should be capable to close a tube and then it should be strong enough to withstand the maximum desirable pressure in the vessel.

2.1. DEA compressor potentials and requirements

2.1.1. Potentials

According to this fact that a DEA compressor has been designed to be compatible with context-awareness standards, its particular form heightens its performance. In the first place, this particular form reduces effects of aerodynamics on a compressor performance. The air mass flow rate and its inlet velocity are two highly influential factors in a conventional compressor performance [7]. On the contrary, while the air mass flow rate sucked by the cells plays key role in a DEA compressor performance, its velocity effects are limited to the stagnation properties at a compressor inlet.

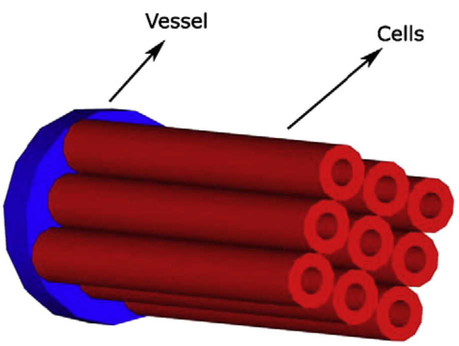

Fig. 1. DEA compressor schematically indicated by two major parts.

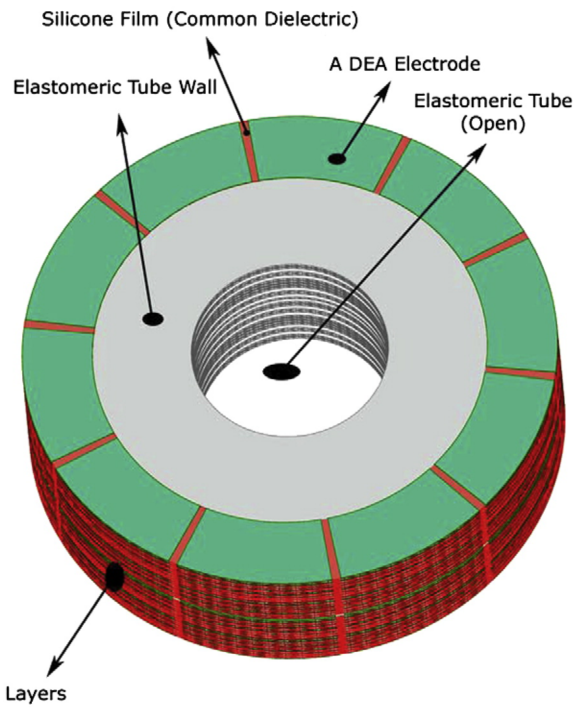

Fig. 2. A ring encompassing tube schematically depicted by its sections at switch on (Tube open).

In fact, a DEA compressor construction involves other influential factors which allow a dynamic change of operation based on condition. A particular method to suck the air provides proper capability for adaptation of a compressor operation to working conditions. By changing each cell pushing airflow frequency in different conditions superior adaptation ability can be created. It produces a variable swallow capacity in the different positions of a compressor leading edge compatible with the inlet airflow. Additionally, by intelligently changing the vessel inflation and depletion frequencies as well as its volume, a dynamic ability to adapt to the working condition can be added to the compressor.

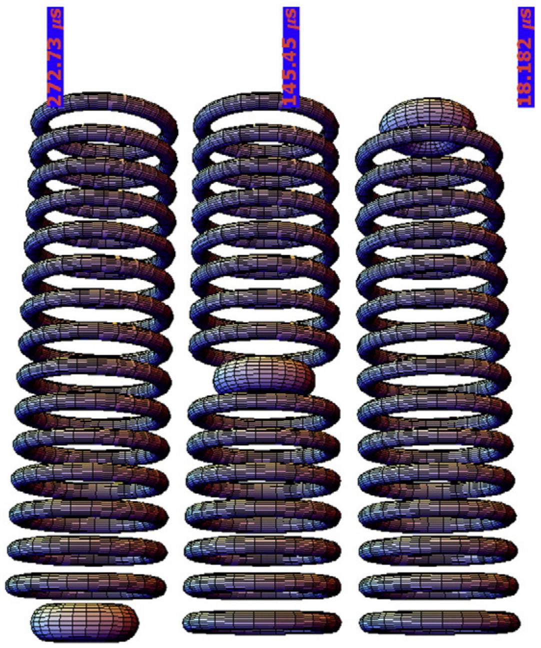

Fig. 3. Movement of the knot by switching off the rings from cell tip towards its root schematically depicted among the 15 rings, along with needful times for such a movement in three steps.

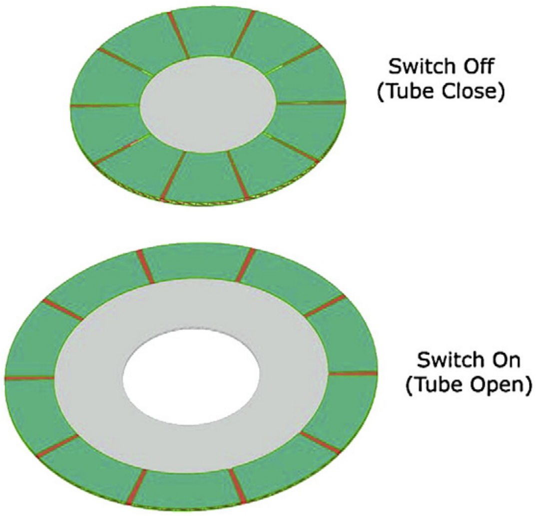

Fig. 4. A layer of each ring consisting of several DEA at switch on and off.

These superior capabilities depend directly on the response speed of the dielectric elastomer. This speed also affects the compressor dimensions. Considering the frontal area of a compressor should commonly be set to the minimum allowable in the propulsions, the number of cells may create a weak point for this device. The longer response time for a given dimension yields less number of the rings in each cell for a given pushing frequency. On the other hand, the lower number of rings, the higher number of cells necessary to push the desirable airflow into the vessel.

However, a DEA compressor construction allows arranging the cells in the shapes capable to contain numerous cells by relatively low frontal area such as internal area of a cylinder and so on.

Besides, according to this fact that the mechanical transmission of the power is not suitable for a DEA compressor configuration, it has well compatibility with the power transmission considered for a context-aware compressor [3].

Additionally, as each DEA is a capacitor, the electric current flows through that is less than a micro ampere. As a result, the energy consumption of each DEA is very low, despite high operating voltage of the system. This fact causes a DEA compressor to consume appreciably less energy than conventional types.

This is clear that compressing a unit volume of a gas to the desirable pressure needs a certain amount of energy and then a DEA compressor needs same power as conventional types to operate. Nevertheless, this power is mostly paid by molecular properties of dielectric elastomers. In fact, two important characteristics of DEA cause low energy consumption for this compressor. One is its mechanism to squeeze based on the Coulomb force and the Maxwell stress and the other is its elastomeric characteristic making dielectric elastomer recover the original size with enough force when electric field is off.

Considering a compressor consumes a big part of the power generated by a turbine, this low driving power promises gas turbines by low fuel consumption in comparison with conventional types.

2.1.2. Response speed

The response speed is the most crucial factor for adapting DEAs to intended configuration. Although response speed of DEAs is a function of different factors such as actuator size and configuration as well as driving electronics, the [4] presents some simple direct measurements of the speed of response that can provide rough but useful estimates. The [4] notes that electrostatic forces on electrodes generate the electromechanical response; as a result, any considerable delay linked to the intrinsic response mechanism of the polymer is not expected. This fact that the dielectric constant of materials does not change dramatically over a range of 100 Hz to 100 kHz supports this assumption. According to the [4] essential limitation for the response speed is the speed of sound, the speed at which the pressure wave would be able to propagate through the material. Thereby the thinner polymer layers, the less propagation time. In fact, this time can be reduced up to millionth of a second. As a whole, response speed limitation is due to the mechanical resonance of the actuator and driven load.

Another limitation is due to RC time constant of the actuator. As surface resistivities of electrodes commonly are on the order of tens to hundreds to thousands of ohms, so the RC time constant does not play key role to limit response time for most small devices [4].

Accordingly, in this work it was assumed that the rings elongate under electric field immediately and return to its own original size forthwith switching off the electric field. Operating frequencies of the cells and the vessel were selected based on this assumption and toward creating optimum dimensions and performance for the design.

3. Modeling methodology

To evaluate the concept, computer modeling could be helpful. The goal is to model the electromechanical behavior of dielectric elastomer actuators with intended configuration based on experiments. The models should allow simulating behavior of the geometrically suitable actuators to optimize the design and to ensure their reliability. A proper material should be selected based on the results generated with this model. The [8] suggests such a mathematical model for the silicone and the acrylic 3 M VHB™4910. Its researches have been carried out toward a great program with participants from the *Technical University of Denmark*, *Risø National Laboratory* and the industrial company *Danfoss A/S*.

Accordingly, the result data of the [8] was firstly considered for selecting suitable dielectric elastomer. Between the polymers surveyed by the [8], VHB™4910 is capable to stretch more than silicone film, and it also can withstand more pressure. Similarly, its breakdown voltage is higher, which causes more strain. The [4] experiences with two types of the silicone films and the VHB™4910 also confirm this fact. Nevertheless, as Fig. 5 illustrates the return curve of this dielectric elastomer does not follow the initial curve and it lies at the lower forces. The [8] relates this weakness to disentanglement of the constituent polymer chains. The results of the [8] experiences about the VHB™4910 can be found in the [9].

Considering the design structure, return force of the rings is crucial to push air in the vessel, and then the acrylic VHB™4910 has a strong weakness to use in the DEA compressor. The silicone film behaves more suitably toward rings demands, yet, its usage may be challenging. First, pre-strain capability of the silicone film is not sufficient and accordingly it cannot generate enough force. Second, resultant data of the [8] shows that at breakdown voltage, when an external weight is applied, the strain of the silicone film is between 10% and 12% indicating elongation less than requirements.

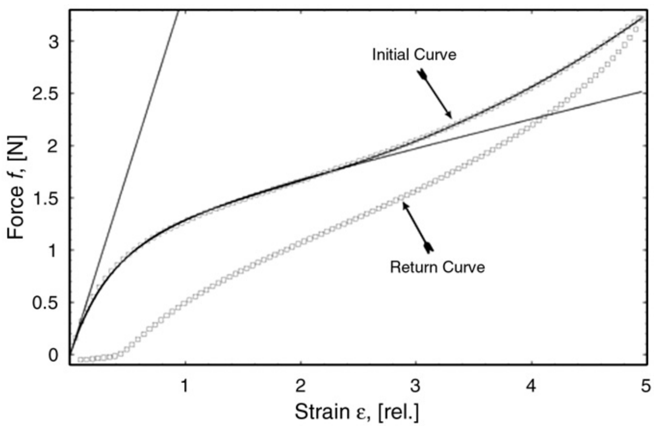

Fig. 5. Force–strain measurement of VHB™4910 actuator, pre-strained 500% in the width direction. Initial length was 5.0 mm; the width was 100 mm, and the thickness 0.167 mm. The measured tensile modulus, from the Hooke model, was 105 kPa. The two-term Ogden fit parameters $\mu_1 = 68.5$ kPa, $k_1 = 0.700$ and $\mu_2 = 767$ kPa, $k_2 = 3.441$ providing an excellent fit in the whole range (for more detail, see [8,9]).

As a result, to achieve desirable expansion in the rings, using several DEA segments in each layer is necessary (Fig. 4). On the other hand, implementing more than one layer is needed to generate sufficient force around a tube (Fig. 2).

3.1. Designing and modeling processes

First step of the design encompasses estimation of the rings/layers number and device dimensions. The force of each ring at the switch off, caused by the pre-strain, and its expansion at the switch on, caused by the electric field, determine these requirements. To measure capabilities of the design, two major curves for intended DEA should be drawn: the force–strain and the voltage–strain curves.

Besides geometries of the design, energy consumption is also important, and then the voltage–current curve should similarly be drawn to estimate operating current for each DEA.

Whether the strain–force behavior is considered under electric field or not, during elongation the dielectric elastomer volume remains constant. Hence, as the length is rising the thickness and the width are shrinking. Thereby, if final length is defined as $I = I_0\alpha$ the width and the thickness are defined as follows respectively [10]:

$$w = \frac{w_0}{\sqrt{\alpha}}$$

$$t = \frac{t_0}{\sqrt{\alpha}}$$

To design each DEA, the form used by the [8] is considered in which the silicone film is covered by the silicone glue as rubber electrodes. This reference has used the *Ogden* model [11] adapted purposefully to simulate this DEA behavior.

To verify reliability of the Ogden model work of the [12] may be considered. This reference used the Ogden model from the package ANSYS to analyze two types of the HSIII silicone specimens: (1) narrow electrode actuators with a regular inactive edge of 20 mm width, and (2) narrow electrode actuators with a narrower inactive edge of 6 mm width. As the Fig. 6 (A through D) illustrates, the results of the finite element analysis have a good agreement with experiments for all the specimens (see the [12] for more detail).

The [8] has applied a two-term model, one is used to fit the dielectric film and the other is adapted for the electrodes. In the electrode part the extension ratio, α is multiplied by a factor, λ so that this part can find its own zero length. This reference defines a particular function, $\theta(\varepsilon)$ to remove electrodes fitting term in the low strain. Final form of the function is as follows:

$$F(\alpha) = t_0 w_0 \left[\mu_1\left(\alpha^{k_1-1} - \alpha^{-1-\frac{1}{2}k_1}\right) + \theta(\varepsilon)\mu_2\left((\lambda\alpha)^{k_2-1} - (\lambda\alpha)^{-1-\frac{1}{2}k_2}\right)\right].$$

in which:

$$\varepsilon = \alpha - 1$$

$$\theta(\varepsilon) = \frac{1}{\left(1 + \exp(\frac{\varepsilon_0 - \varepsilon}{\Delta\varepsilon})\right)}.$$

The [8] has showed that this function results in a reliable fit to the empirical data if the following values are considered for its parameters:

$$\mu_1 = 388\,\text{KPa} \quad k_1 = 1.003$$
$$\mu_2 = 16.7\,\text{Pa} \quad k_2 = 6.03$$
$$\lambda = 2.948$$
$$\varepsilon_0 = 0.67 \qquad \Delta\varepsilon = 0.06.$$

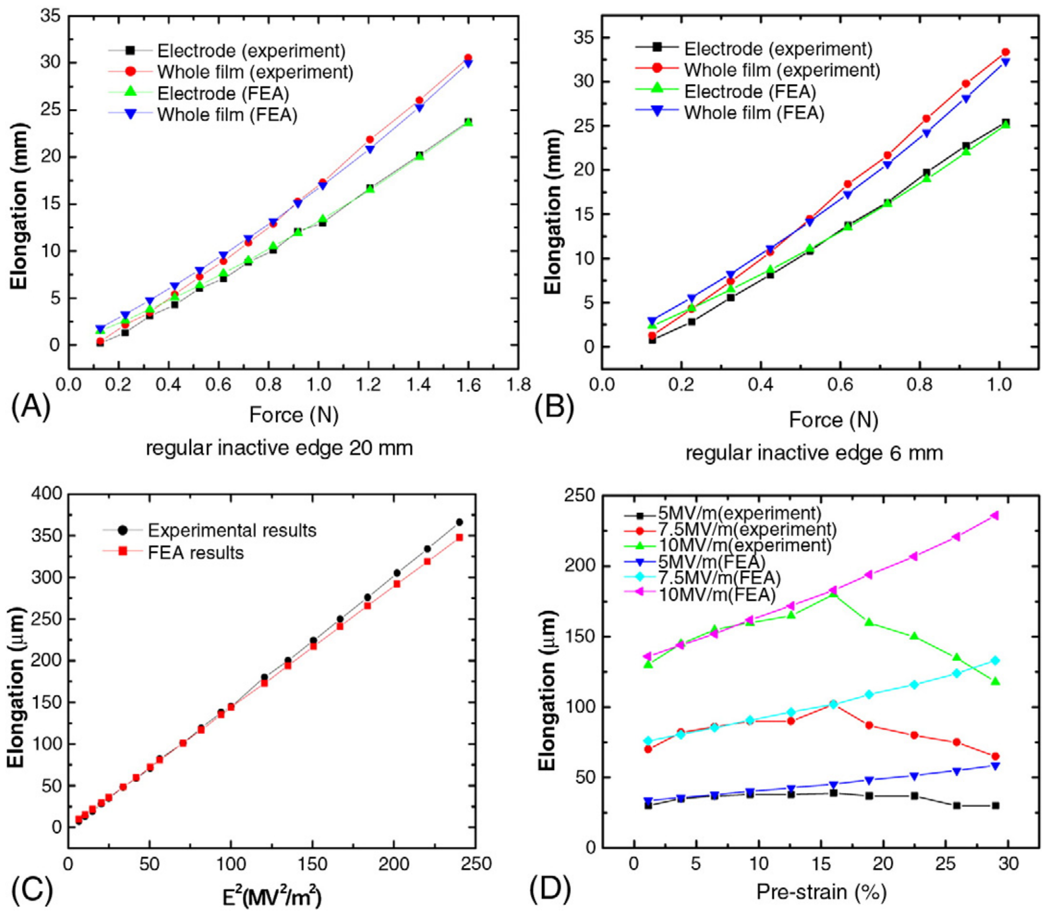

Fig. 6. Comparison of Ogden model with empirical data (see [12]).

The function, $F(\alpha)$ cannot represent the force applied by the rings on a tube, therefore another component should be added to define the force. Each layer considered for rings consists of a dielectric elastomer whose faces are divided to certain number of DEA by their electrodes. It means all the DEAs on a layer have a common dielectric (Fig. 4), as a result, for defining F_{ring} the following equation is considered:

$$F_{ring} = N_{layer}\,F(\alpha) + F_{tube} \quad (1)$$

where F_{tube} shows the opposite force generated by an elastomeric tube.

The tube tolerable pressure is measured as follows:

$$P_{tolerable} = {}^{F_{ring}}\big/_{A_{ring}} \quad (2)$$

where A_{ring} shows each ring contact area with a tube. This area is a function of a ring thickness and considering a ring thickness is changing during expansion, it is defined as follows:

$$A_{ring} = \left({}^{(t_0 \; + \; t_{0\,electrode})}\Big/_{\sqrt{\alpha}} \right) D_{tube}\,\pi.$$

The ring dimension is calculated according to its generated force and tolerable pressure. Additionally, the pre-strain required to create desirable pressure $P_{tolerable}$ and number of the layers are measured based on these properties.

The [8] focuses on liner movement of DEAs, and to model their behaviors under electric field, it implements the following force equation:

$$\sum F = mg + F_{electric} + F(\alpha)$$

However, resulting force is not a subject to study here, rather the focus is on the strain and the energy consumption. For actuators, mg represents the load applied on the system, which helps the elongation. With regard to the cells configuration, the force applied by an elastomeric tube on the rings represents this opposite force. Therefore, the following equation was concluded to indicate the force equilibrium in each ring:

$$\sum F = F_{electric} + F_{ring} \quad (3)$$

where [13]:

$$F_{electric} = \frac{t_0}{w_0}\, d\, d_0\, V_m^2\, \alpha.$$

Both $F_{electric}$ and F_{tube} are taken into account as the opposite forces, thereby they appear by negative signs in the calculations.

The current and the voltage of the electric filed are calculated to estimate the strain of the DEAs and their required energy. The AC voltage is considered to generate the electric field, and the AC behavior of capacitors is considered for the DEAs. In such condition, the voltage and the current are defined as follows:

$$V = V_m \cos\omega t = V_m e^{i\omega t}$$
$$I = I_m \cos(\omega t - \phi) = I_m e^{i(\omega t - \phi)}.$$

where ϕ represents a lag of phase between the voltage and the current, which is considered equal to 90°. The DEA complex impedance is indicated by the [14]:

$$Z = \frac{-i}{\omega C}.$$

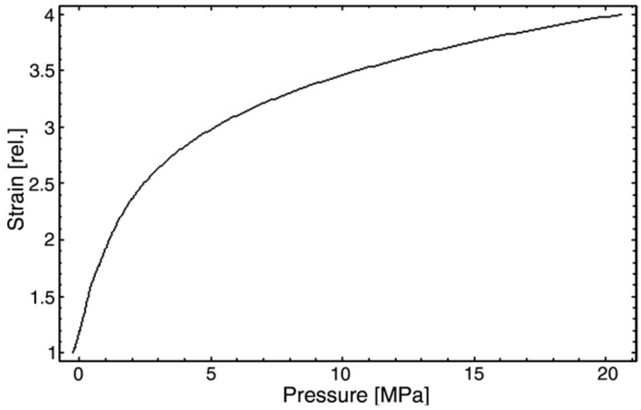

Fig. 7. The variation of tolerable pressure versus strain for a ring consisting of 20 layers.

As a result, the circuit current representing the current used by each DEA is defined as:

$$I_m = C e^{\frac{-i\pi}{2}} \omega V_m \tag{4}$$

where $\omega = 2\pi f$ and C represents the capacity of the capacitor calculated by the following equation:

$$C = d d_0 \frac{A_{\text{electrode}}}{t_0}. \tag{5}$$

Calculating the DEA capacity, the energy consumed in a DEA in Watt is measured by the following equation:

$$W_{DEA} = V_m I_m. \tag{6}$$

To set the system dimension, first α should be estimated. The parameter α represents total strain in a layer, so it is defined as:

$$\alpha = N_{DEA} \times \alpha_{DEA}.$$

Determining α, the diameter of the rings according to the applied electric field is estimated, which opens the door to calculate a tube dimension. The tube dimension determines the air volume that a cell will be able to push into the vessel in a period.

4. A sample model

For preliminary estimation of such a device performance, the author designed and modeled a sample compressor.

The desirable performance for the sample and its inlets at static condition were defined as follows:

Overall pressure ratio: 1:10
Air mass flow: 1 kg/s
Inlet temperature: 288 K
Inlet pressure: 1 bar

The characteristic of a layer was considered similar to the silicon film actuator provided and examined by the [8]. Therefore, two back-to-back layers of the silicone film by thickness $t_0 = 26$ µm were considered as a dielectric, and thus, the total thickness of a dielectric was 52 µm. The [8] has applied the sprayed electrode on a layer of the silicone film whose thickness was estimated between 5 and 20 µm in the different positions. For the sample, average of these values was considered as the thickness of the electrodes, accordingly, total thickness of the electrodes was $t_{0\ \text{electrode}} = 25$ µm. With regard to desirable strength of each layer of the rings, width of a DEA was set to $w_0 = 1000$ µm.

Using Eq. (2), the curve of a layer bearable pressure versus its strain was drawn. The Fig. 7 represents such a curve for a ring consisting of 20 layers.

Each ring should withstand the pressure equal to 1 MP. As the Fig. 7 shows, 100% pre-strain ($\alpha = 2$) for a layer of the silicone film was set, by which each ring is capable to generate the pressure about 1.13574 MP.

Using Eq. (3), behavior of a layer under electric field was evaluated. Intending a strain about 10% for a DEA under electric field, to produce an expansion approximately 100% in a layer, 10 DEAs were considered. Additionally, to generate desirable strain in the rings F_{tube} should be set to proper value, and accordingly, it was considered equal to weight of mass12 g.

The process depends on finding α from Eq. (3), and with regard to this fact that the equation is not exponential a numerical method should be implemented. Hence, the routine *FindRoot* in the *Mathematica 5.0* was used [15]. Afterward, to evaluate the cells behavior under electric filed, applied voltage was varied from zero to 3000 V and the strain–voltage curve was drawn (Fig. 8). The experiences of the [8] have shown the silicone film breakdown field is about 5 MV/m, and then, a voltage equal to 2600 V was considered for the applied electric field.

Using Eq. (5), the coequal capacity of a DEA is calculated, which needs estimation of the electric current circulated in each DEA. Accordingly, the frequency equal to 50 Hz was considered for the AC current and the energy consumption in each DEA is measured by the Eq. 6. The Fig. 9 indicates the current–voltage curve obtained for the model. As the graph indicates at 2600 V each DEA current is about 6.65662×10^{-7} A.

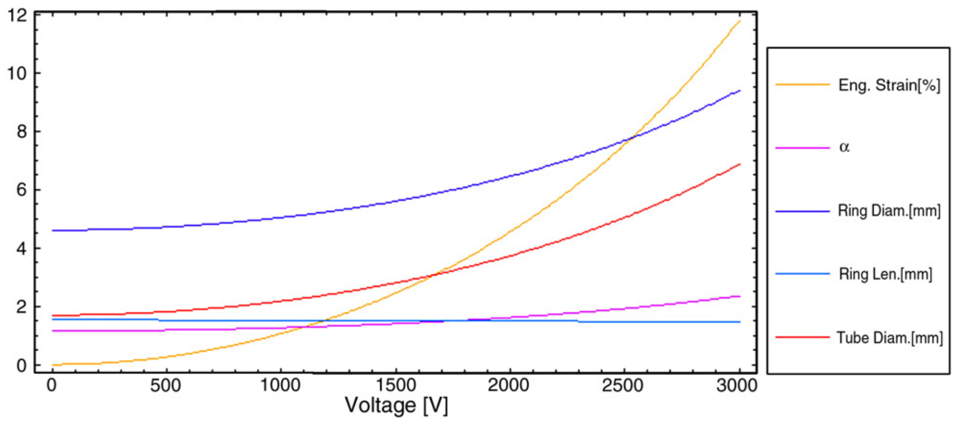

Fig. 8. Variation of strain and ring dimensions versus applied voltage.

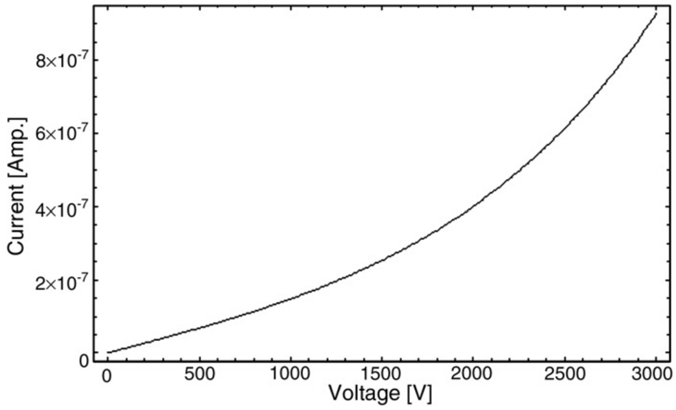

Fig. 9. Variation of current in each DEA versus voltage.

The Fig. 8 shows the variation of a ring and a cell dimensions measured toward total generated by all the DEAs in each layer. Measuring these dimensions, the volume of a tube is estimated. This volume leads the calculation to estimate the air mass flow that a cell is capable to push. This mass in a period is calculated by the following equation:

$$m_{\text{tube}} = \rho V_{\text{tube}} \tag{7}$$

in which the air density ρ is calculated according to the inlet condition:

$$\rho = \frac{P_1}{RT_1}. \tag{8}$$

The volume V_{tube} is a function of the rings number, N_{ring} which should be set purposefully. For axial-flow compressors, frontal area is commonly set based on inlet axial velocity of the air and selection of this velocity is important because of its effects on first stage aerodynamics [16]. Generally, the inlet axial velocity on the order of $C_a = 150$ m/s is known as proper value for the axial-flow compressors with the function and the size similar to that is intended in this study [7]. Using the following equation, this axial velocity results in an area about 0.0022 m^2 at similar inlet condition:

$$A = \frac{m}{C_a \rho}.$$

Consequently, the author selected 550 rings for the sample that creates a same total area for the entrance at switch on.

In this case, the frequency by which a cell pushes the air f_{cell} has a key role to measure real air flow. In the sample, this frequency was set to 100 Hz, a value twice as much as the frequency considered for the vessel depletion. This frequency is necessary to calculate the vessel volume; yet, firstly, the temperature of the compressed air should be calculated with regard to thermodynamic process. Hence, the following equation is used [7]:

$$T_2 = T_1 \left[\frac{P_2}{P_1}\right]^{\frac{n-1}{n}}$$

where $\frac{n-1}{n} = \frac{1}{\eta_\infty} \times \frac{\gamma-1}{\gamma}$.

Considering the compression process in the intended cells is very elementary beside conventional compressors, the Polytropic efficiency $\eta_\infty = 0.98$ is a rational value for this process [7].

Estimating temperature of the compressed air, its volume, V_{unit} is calculated by implementing the Eqs. (7) and (8). The vessel volume is calculated as follows:

$$V_{\text{vessel}} = \frac{1}{f_{\text{vessel}}} \left(\frac{V_{\text{unit}}\, m}{m_{\text{tube}}}\right).$$

The following relation determines the number of the cells necessary to serve such a vessel:

$$N_{\text{cell}} = 1 + Round\left[\frac{V_{\text{vessel}}}{\frac{f_{\text{cell}}}{f_{\text{vessel}}} V_{\text{tube}}}\right].$$

During operation, one of the rings would always be switched off to create the knot moving from a cell tip to its root (Fig. 3); as a result, following relation is used to calculate the power required to operate each cell:

$$W_{\text{cell}} = W_{\text{DEA}} N_{\text{DEA}} N_{\text{layer}} (N_{\text{ring}} - 1).$$

Then overall driving power was estimated as:

$$W = N_{\text{cell}} W_{\text{cell}}.$$

5. Results

Using computer modeling a sample compressor was designed and modeled with a novel configuration based on DEA to qualify potentials of the concept.

Following specifications were obtained for the sample model:

Overall pressure ratio 1:10
Inlet temperature 288 K
Inlet pressure 1.0 bar
Exit temperature 563.557 K
Overall air mass flow rate 0.02 $\frac{\text{Kg}}{\text{s}} \times \frac{1}{f_{\text{Vessel}}} = 1.0$ kg/s
Needful power to drive 17.103 kW kg/s

Cells swallow frequency 100 Hz
Vessel depletion frequency 50 Hz
AC voltage frequency 50 Hz
Driving voltage 2600 V
Current circuited in each DEA 6.65662×10^{-7} A.

Layers number in each ring 20
DEA number on each layer 10
Rings number in each cell 550
Cells number 90
Tube overall diameter at switch off (Total tube walls thickness) 2 mm (Close)
Tube internal diameter at switch on 5.35456 mm (Open)
Cell length at switch on 807.853 mm
Cell length at switch off 840.617 mm
Cell diameter at switch on 7.97054 mm
Cell diameter at switch off 4.60976 mm

Available time for each ring to pulse (time to open and close) 200/11 ≈ 18.182 μs (Fig. 3)
Necessary area for the tubes at switch on 0.00202666 $_{\text{m2}}$
Necessary area for the cells at switch on (overall area) 0.00449064 $_{\text{m2}}$
Vessel volume 0.00323482 $_{\text{m3}}$

The first parameter important for the comparison is the energy consumption. According to thermodynamic principles in an adiabatic process required power to compress unit mass of a gas is calculated based on the temperature rise in the process. The following equation is commonly used to calculate the power required to raise the gas temperature from T_1 to T_2 in an adiabatic compression [7]:

$$W = c_p(T_1 - T_2)$$

If specific heat of the air in constant pressure is considered $c_p =$ 1.005 kJ kg/K, to raise temperature from 288 K to 563.557 K the required power is 276.935 kW kg/s. This value shows that the DEA compressor potentially needs much less energy than conventional types. With regard to the discussion in the section 2, this capability is because of dielectric elastomer properties.

6. Conclusion

Based on DEA capabilities a novel type of compressor was designed and modeled by computer. This compressor uses some gullet like tubes made of DEAs to inflate a vessel by high frequency. The vessel is depleted when its inlet pressure rises up to the desirable value. The depletion frequency is also high to create a steady flow of the compressed air.

The study was aimed at designing and modeling a compressor with two major capabilities: first, suitable performance and configuration to operate in gas turbine engines, and the second, supporting context-awareness. Because of the particular properties of dielectric elastomers, low energy consumption in comparison with conventional types was also expected.

The results of the preliminary modeling show a good agreement of the DEA compressor capabilities and requirements. However, two major issues linked to DEAs characteristics remain open:

- In this study, the dimensions and the device work frequencies were determined based on this assumption that DEA reacts to electric field immediately. However, this characteristic should be determined for the intended configuration; afterward, its dimensions and allowable work frequencies should be set.
- A compressor as a component of gas turbine engines should be capable to operate reliably. In fact, service cycle of a compressor should be long enough to satisfy the requirements. Capability of intended DEA to operate for an acceptable time in such a high frequency is the issue that should be determined by experiments, tests and studies. Obviously, the most proper polymer should be selected, which can withstand the acceptable time under such a tough operating condition.

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