Politico-Engineering–Politically-Initiated Engineering in Piezoelectric Devices

Kenji Uchino*

Office of Naval Research, Japan & Int'l Center for Actuators & Transducers, The Penn State University, University Park, USA

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*Corresponding author: ONR Global-Asia, Office of Naval Research, Roppongi, Minato-Ku, Tokyo 106-0032, Japan; & Int'l Center for Actuators & Transducers, The Penn State University, University Park, PA 16802, USA, Tel: 03-6385-3250; Fax: 03-6385-3254; E-mail: Kenji.Uchino.civ@mail.mil, Kenji-Uchino@psu.edu

Abstract

There are primarily four factors that have influences on engineering: Social/culture/religion, Technology/science, Economics, and Politics/law. I propose them as "STEP" using their initials. The strength of the impact of these factors becomes different according to history. Alchemy of the 16th century is an example of "Socio-Engineering". From the Christian doctrine, "Copernican (Heliocentric model)" was denied, but "alchemy" was approved. Religion was controlling science. In the 17th and 18th centuries, people were solved from the spell of religion and engineering based on science and technology (S&T), so-called "Techno-Engineering" is respected instead. In the 18th and 19th centuries, technologies for mass production at low manufacturing cost were required and "Econo-Engineering" became the mainstream; i.e., technologies that are essential to enhance national strength. The intention of increasing national wealth and military strength increased friction and that led to the First and Second World Wars in the 20th century. Engineering of this period is mainly government-led production of war weapons, and it was a beginning of "Politico-Engineering". After the Wars, mass production technologies for the reconstruction/recovery revived, and "Econo-Engineering" continued until 1980s in the world. When the 21st century began, as a consequent result, environmental degradation, resource depletion, and food famine have become major problems, in addition to the worldwide worry about terrorist attacks. Global regulations are strongly called, and the government-initiated technology, that is, "politico-engineering" has become important again in order to overcome the regulations.

This paper overviews the current "politico-engineering (politically-initiated engineering)"; technologies for the society sustainability and crisis technologies for natural disaster, infectious disease, enormous accident, terrorist/criminal incident, and war/territorial invasion, taking into account future actuator/sensor development directions.

Keywords: Politico-engineering; Piezoelectric devices; Sustainable society; Pb-free piezoelectrics; Energy harvesting; Crisis technology

Introduction

The world-largest earthquake and tsunami attacked northern part of Japan Honshu Island on March 11th, 2011, and 19,000 people seemed to have deceased. Further, the problem of the

accident at the Fukushima Daiichi Nuclear Power Plant induced by the tsunami seems to be more significant than the earthquake/tsunami incident itself, though there was no one killed directly from the Power Plant accident. After three years from the accident, the Fukushima problem (i.e., Cs contamination) is still ongoing.

There were problems at several stages. First is about the prediction of earthquakes and tsunamis. Indeed, an accurate prediction of earthquakes and tsunamis is limited in the current scientific capability. However, I regret that there was not sufficient monitoring and public reporting system once happened. Second problem is about the initial action after the nuclear accident. The Fukushima nuclear power plant "melt-down" occurred as a result of unexpectedly large earthquake/tsunami and consequent electric shut-down, but the crucial difference between Three-Mile-Island accident (Pennsylvania in 1979) and Fukushima accident was the "explosion" at the Fukushima facilities. Delay in the cooling process is the major failure in the initial action after the "melt-down" led to this difference. According to the newspaper and television reports, it took three days to start water-cooling nuclear chambers after uncontrolled situation. Why did the delay in decisions and directives of the political leaders happen? It seems to be caused by the political leaders' lack of knowledge on science and technology, in particular, on the risk management. It is difficult for Tokyo Electric Power Company (TEPCO) to respond to the crisis by itself, because it does not keep either robots or ability to respond to the crisis. Risk management of major accidents in Japan is within the jurisdiction of the Ministry of Defense, and the Commander in Chief of Defense is the prime minister. The author finds it difficult to escape from the thought that the delay in the Chief Commander's decision brought about "explosion", and insists on the urgent necessity of the "*politico-engineering*" aspect in the Japanese society.

Extending key issues in the above example, this paper overviews the current "politico-engineering (politically-initiated engineering)"; technologies for the society sustainability and crisis technologies for natural disaster, infectious disease, enormous accident, terrorist/criminal incident, and war/

territorial invasion, taking into account future actuator/sensor development directions in particular.

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Historical Aspects of Engineering

There are primarily four factors that have influences on "engineering": (1) Social/culture/religion, (2) Technology/science, (3) Economics, and (4) Politics/law. Though normal MBA classes teach them as "PEST" using their initials, I propose intentionally as "**STEP**", taking into account the historical sequence.

Socio-Engineering: The strength of the impact of these factors becomes different according to the history. Alchemy (technology of turning base metals into the noble metals such as gold or silver) of 16th century is an example of "**Socio-Engineering**". From the Christian doctrine, "Copernican (Heliocentric model)" was denied, but "alchemy" was approved. The "inquisition" against Galileo Galilei (1564-1642) is one of the most famous anecdotes (**Figure 1**) [1], where he was sentenced to make "abjuration" on his belief. There remains an episode that he muttered "still the earth rotates ..." In a word, "religion" was controlling science in those days.

Techno-Engineering: In the 17th and 18th centuries, people were solved from the spell of religion, and engineering based on pure science and technology (S&T), so-called "**Techno-Engineering**", is respected instead (i.e., Age of Reason and Age of Enlightenment). Isaac Newton (1643-1727) published his "gravitational law", inspired by "apple falling-down", and Benjamin Franklin (1706-1790) clarified the origin of "electricity". Though the gravitational law deduced "Heliocentric" model, Newton was protected because he was a sincere alchemist on the other hand. As the reader probably knows the episode (see **Figure 2**), Franklin used a child's kite to prove that lightning/thunder is really a stream of electrified air (reckless challenge, indeed!).[2]

Econo-Engineering: In the 18th and 19th centuries,

Figure 1: The "inquisition" against "Heliocentric" model by Galileo Galilei (1564-1642) [1].

technologies for mass production at low manufacturing cost ("**Industrial Revolution**") were required and "**Econo-Engineering**" became the mainstream; technologies that are essential to enhance national strength. In the early 18th century, British textile manufacture was based on wool which was processed by individual artisans, doing the spinning and weaving on their own premises. The roller spinning machine (1770s) and the flyer-and-bobbin system developed for drawing wool to a more even thickness dramatically increased the productivity and the labor employment rate in the United Kingdom. James Watt (1736-1819) developed a steam engine (**Figure 3**), which was commercially successful in the application for pumping water out of mines [3].

Politico-Engineering: The intention of increasing national wealth and military strength increased friction and that led to the First and Second World Wars in the 20th century. Engineering of this period is mainly government-led production of war weapons, and it was a beginning of "**Politico-Engineering**".

The piezoelectric device is one of the best examples developed from the politico-engineering.[4] Let us review briefly the history of piezoelectric devices. The Curie brothers (Pierre and Jacques Curie) discovered direct **piezoelectric effect** in single crystal quartz in 1880; that is, under pressure quartz generated electrical charge/voltage. Materials showing this phenomenon also conversely have a geometric strain proportional to an applied electric field. This is the converse piezoelectric effect, discovered by Gabriel Lippmann in 1881. Meanwhile, the Curie brothers put their discovery to practical use by devising the piezoelectric quartz electrometer, which could measure faint electric currents, and helped Pierre's wife, Marie Curie 20 years later in her early research (Techno-Engineering period of Piezoelectricity).

It was at 11:45 pm on April 10th, 1912 that the shipwreck of "TITANIC" happened. As the reader knows well, this was caused by iceberg hidden in the sea. If the ultrasonic sonar system had been developed, it should not have happened. Owing to this tragic incident (social force), ultrasonic technology development

Figure 2: Flying kite experiment in a thunder storm by Ben Franklin (1752) [2].

was motivated by using piezoelectricity, but it did not generate the development investment.

World War I from 1914 (immediately after Titanic accident) created real investment to accelerate the ultrasonic technology in order to search the German U-Boats under deep sea (i.e., Politico-Engineering). Paul Langevin, a professor of the Industrial College of Physics and Chemistry in Paris, started the experiment on ultrasonic signal transmission into sea, in collaboration with French Navy. Langevin succeeded in transmitting ultrasonic pulse into the south France sea in 1917. But, in that period, it was not possible to produce such a large high-quality single crystals [5]. In order to overcome this dilemma, Langevin invented a new transducer construction; small quartz crystals arranged in a mosaic were sandwiched by two steel plates. This sandwich structure is called “*Langevin type*”, which is popularly utilized even nowadays (Figure 4).

The next breakthrough in piezoelectric devices occurred during World War II. Barium titanate (BaTiO_3 , BT) ceramics were discovered independently by three countries, US, Japan and Russia: E. Wainer and N. Salomon in 1942, T. Ogawa in 1944, and B. M. Vul in 1944. Compact radar system development requested compact high capacitance “condensers”. Based on the widely used “Tita-Con (titania condenser)” composed of TiO_2 -MgO, researchers doped various oxides to find higher permittivity materials. The independent discoveries by R. B. Gray at Erie Resister (patent applied in 1946) and by Shepard Roberts at MIT (published in 1947) should be pointed out that the electrically-poled BT exhibited “piezoelectricity” owing to the domain re-alignment. The easiness in composition selection and in manufacturability of BT ceramics prompted W. P. Mason and others to study the transducer applications with these electro-ceramics.

Following the methodology taken for the BT discovery, the perovskite isomorphous oxides such as PbTiO_3 , PbZrO_3 , and SrTiO_3 and their solid solutions were intensively studied. In particular, the determination of the $\text{Pb}(\text{Zr,Ti})\text{O}_3$ system phase diagram by

Figure 3: Engraving of a 1784 steam engine designed by Boulton and Watt [3].

Figure 4: Original design of the Langevin underwater transducer and its acoustic power directivity [5].

Figure 5: Historical aspect of the four factors which influence on Engineering: Socio-, Techno-, Econo- and Politico-engineering.

the Japanese group, E. Sawaguchi, G. Shirane and Y. Takagi [6] is noteworthy, which led to the present PZT period.

Figure 5 summarizes the historical aspect of the four factors which influence on Engineering: Socio-engineering, Techno-engineering, Econo-engineering and Politico-engineering. Notice the significant influential factor change according to the history.

Recent Politico-Engineering: After the wars, mass production technologies were sought for the reconstruction and recovery of the country, and a sort of “Econo-Engineering” revived under the direction of the political leaders until 1990s in Japan. **Figure 6** shows the country power (GDP) change with year for Japan, USA (20 years ahead), and China (30 years behind) visualized by using typical growth curves.

1960s – Domestic Politics

Let us review the product planning strategy taken historically by the Japanese industries. In 1960s, the four-Chinese-character slogan was “*heavier, thicker, longer, and larger*”; that is, manufacturing heavier ships, thicker steel plates, constructing longer buildings, and larger power plants

(dams) were the key strategies for recovering from the ruins of World War II (i.e., **Domestic Politics**). Refer to the initial rise of the growth curve in **Figure 6**. This societal mood made me choose Electrical Engineering in the university to become a water-dam engineer. Though Japanese people became wealthy, subsidiary effects started to surface: i.e., “**industrial pollution**”. The southern part of the sea of Japan was contaminated by the heavy metal (mercury) disposal by Nippon Chisso Company (chemical fertilizer manufacturer), which created thousands of “Angel Babies (missing/dislocated arm disorder)” in that wide area. Steel industries produced air pollution (yellow sky!) and “asthma” even for small kids. Traffic congestion generated severe acoustic noise even in suburban areas. One of the most technological industries, nuclear power plants, leaked hazardous radio-active wastes multiple times. The “melt-down” accident of Three-Mile-Island, Pennsylvania happened in 1979.

1980s – Econo-Politics Revival

A completely opposite slogan started in the 1980s; that is, “*lighter, thinner, shorter, and smaller*”. Printers and cameras became lighter in weight, thinner computers and TVs (flat panel) gained popularity, printing time and information transfer period became shorter, and air-conditioners and tape recorders (“Walkman” by SONY) were smaller. Because of this societal mood, I, as a young university professor then, started working on compact “piezoelectric actuators & motors”. Refer to **Table 1**.

Though the serious industrial pollution diminished gradually during this period in proportion to the country power (high GDP per person), different subsidiary effects started: (1) “greenhouse effect” and “global warming” due to CO₂ gas generated by over-produced automobiles, (2) energy crisis due to over-consumption of energy and lack of fossil energy sources (oil), in addition to the political mismanagement, and (3) population growth due to advanced medical technologies. Longer life time is welcomed by individuals (now the average age for Japanese female is approaching to 87, male, 82 already; the world-eldest). However, over-population of humans will create an imbalance against other animals/natures, and senior population, in particular, causes societal and economic problems (pension, health insurance, work force etc.).

2000s – International Politics

When the 21st century began, as a consequent result, environmental degradation, resource depletion, and food famine

Figure 6: Country power (GDP) change with year for Japan, USA (20 years ahead), and China (30 years behind) visualized by typical growth curves.

1960s	Heavier	--	Ship manufacturing
	Thicker	--	Steel industry
	Longer	--	Building construction
	Larger	--	Power plant (dam)
1980s	Lighter	--	Printer, Camera
	Thinner	--	TV, Computer
	Shorter	--	Printing time Communication period
	Smaller	--	"Walkman" Air conditioner
2000s	Cooperation	--	Global standard – internet
	Protection	--	Defense technologies
	Reduction	--	Pb, Dioxin, CO ₂ Energy consumption
	Continuation	--	Food supply Population–Med technology

Table 1: Technology development paradigm in Japan after World War II.

have become major problems. Global regulations are strongly called, and the government-initiated technology, that is, “**politico-engineering**” has become further important again in order to overcome the regulations. The author would like to propose in this paper a new four-Chinese-character keyword for the era of “politico-engineering”, “**cooperation, protection, reduction, and continuation**”. Global coordination and international cooperation in standardization of internet systems and computer cables became essential to accelerate the mutual communication. The **Kyoto Protocol** in December 1997 is an international agreement linked to the United Nations Framework Convention on Climate Change [7]. Its major feature is to set binding targets for 37 industrialized countries and the European community for reducing greenhouse gas emission. *Protection* of the territory and environment from the enemy or natural disaster, and of infectious disease spread is mandatory. *Reduction* of toxic materials such as lead, heavy metals, dioxin, and of the use of resources and energy consumption is also the key, and the society *continuation*, i.e., **status quo** or **Sustainable Society**, is important to promote.

Table 1 summarizes the technology development paradigm in Japan after World War II so far discussed. Considering situation in the world such as terrorist attacks, territorial aggression, major disasters (natural and human), we will discuss “**crisis technologies**”, in addition to the **sustainability technologies** as “**politically-initiated engineering**” in the following sections.

Sustainability Technology

One of the **normal technologies**, which are initiated politically, is the sustainability technology. The sustainability technologies include:

- Power and energy (lack of oil, nuclear power plant, new energy harvesting)
- Rare material (rare-earth metal, Lithium)
- Food (rice, corn – bio-fuel)
- Toxic material
- Restriction (heavy metal, Pb, Dioxin)

- Elimination/neutralization (Mercury, Asbestos)
- Replacement material
- Environmental pollution
- Energy efficiency

The author discusses this issue here in the piezoelectric device area, where the sustainable society requires (a) usage of *non-toxic* materials, (b) *disposal technology* for existing hazardous materials, (c) reduction of *contamination gas*, (d) new *energy source* creation, and (e) *energy-efficient* device development.

Energy Efficiency

Electric components such as motors and transformers are mostly based on electromagnetic transduction at present. With reducing their size (power level less than 30W), the efficiency of these electromagnetic components reduces drastically due to the Joule heat in their thin coil wire (i.e., the resistivity in the coil becomes significant). Thus, piezoelectric actuators and transducers with much less losses are highly sought after in the 21st century. In the past 30 years (i.e., after the 1980s), most researchers put efforts on improving the piezoelectric performance from the “real-part” property’s viewpoint: that is, improved displacement, force, responsivity etc. An example from this approach created single crystals based on $\text{Pb}(\text{Zn}_{1/3}\text{Nb}_{2/3})\text{O}_3\text{-PbTiO}_3$, which were discovered by our group [8], and now have become widely researched for medical and underwater applications. However, from the viewpoint of efficiency and reliability such as heat generation or performance degradation under high voltage/power drive, the key is the “imaginary-part”; that is, “*loss and hysteresis mechanisms*”. Thus, in the 2000s the author, as a senior professor, has been studying loss mechanisms in piezoelectrics, including high-power characterization system (HiPoCS) [9], and practical high-power piezo-ceramics, in addition to highly energy efficient compact piezoelectric actuators and transducers.

Usage of Non-Toxic Materials

21st Century is called “The Century of Environmental Management.” In 2006, European Community started RoHS (Restrictions on the use of certain Hazardous Substances), which explicitly limits the usage of lead (Pb) in electronic equipment. Basically, we may need to regulate the usage of lead zirconatetitanate (PZT), most famous piezoelectric ceramics, in the near future. The Japanese and European communities may experience governmental regulation on the PZT usage in 2016. Pb (lead)-free piezoceramics have started to be developed after 1999, which are classified into three; $(\text{Bi},\text{Na})\text{TiO}_3$, $(\text{Na},\text{K})\text{NbO}_3$ and tungsten bronze.

The share of the patents for bismuth compounds (bismuth layered type and $(\text{Bi},\text{Na})\text{TiO}_3$ (BNT) type) exceeds 61%. This is because bismuth compounds are easily fabricated in comparison with other compounds. Note that the toxicity of Bi^{3+} is not very low compared with Pb^{2+} , but that a regulation may not be proposed because this atomic element is not familiar to

politicians fortunately. Langevin transducers used popularly for underwater fish finders and hydrophones are also utilized for ultrasonic cleaning and hazardous material dissolving systems. For these ecological applications, it is reasonable to make the systems also environment-friendly. Honda Electronics, Japan developed Langevin transducers with using the BNT based ceramics for ultrasonic cleaner applications [10]. The composition $0.82(\text{Bi}_{1/2}\text{Na}_{1/2})\text{TiO}_3\text{-}0.15\text{BaTiO}_3\text{-}0.03(\text{Bi}_{1/2}\text{Na}_{1/2})\text{-(Mn}_{1/3}\text{Nb}_{2/3})\text{O}_3$ exhibits $d_{33}=110\times10^{-12}\text{C/N}$, which is only 1/3 of that of a hard PZT, but the electro-mechanical coupling factor $k_t=0.41$ is larger because of much smaller permittivity ($\epsilon=500$) than that of the PZT. Furthermore, the maximum vibration velocity of a rectangular plate (k_{31} mode) is close to 1 m/s (rms value), which is higher than that of typical hard PZTs.

$(\text{Na},\text{K})\text{NbO}_3$ (NKN) systems exhibit the highest performance because of the morphotropic phase boundary usage. Figure 7 shows the current best data reported by Toyota Central Research Lab, where strain curves for oriented (or textured) and un oriented $(\text{K},\text{Na},\text{Li})(\text{Nb},\text{Ta},\text{Sb})\text{O}_3$ ceramics are shown [11]. Note that the max strain reaches up to 1500×10^{-6} , which is equivalent to the PZT strain. Drawbacks include their sintering difficulty and the necessity of the sophisticated preparation technique (topochemical method for preparing flaky raw powder).

Tungsten-bronze (TB) types are another alternative choice for resonance applications, because of high Curie temperature and low loss. Taking into account general consumer attitude on disposability of portable equipment (printers, cellular phones), Taiyo Yuden, Japan developed micro ultrasonic motors using non-Pb multilayer piezo-actuators [12]. Their composition is based

Figure 7: Strain curves for oriented and un oriented $(\text{K},\text{Na},\text{Li})(\text{Nb},\text{Ta},\text{Sb})\text{O}_3$ ceramics [11].

on tungsten bronze (TB) $[(\text{Sr},\text{Ca})_2\text{NaNb}_5\text{O}_{15}]$ without heavy metal or even K (potassium seems to be a little toxic in comparison with Na). The basic piezoelectric parameters in TB ($d_{33}=55\sim80$ pC/N, $T_c=300^\circ\text{C}$) are not very attractive. However, once the c-axis oriented ceramics are prepared, the d_{33} is dramatically enhanced up to 240 pC/N. Further since the Young's modulus $Y_{33}^E=140$ GPa is more than twice of that of PZT, the higher generative stress is expected, which is suitable to ultrasonic motor applications. Taiyo Yuden developed a sophisticated preparation technology for fabricating oriented ceramics with a multilayer configuration: that is, preparation under strong magnetic field, much simpler than the flaky powder preparation. Since most of piezo-ceramics are diamagnetic, the ceramic powder suspended in slurry will be aligned along its magnetically-stable axis under a strong magnetic field (such as 10 T). Because the polarization axis in their particular TB composition corresponds to the magnetically-unstable axis, they used the magnetic field parallel to the green sheet. A cut-green-sheet was rotated practically under steady magnetic field during drying period.

Figure 8(a) shows their compact rotary ultrasonic motor with a piezoelectric multilayer actuator (MLA) [12]. A cantilever rod is wobbled by a 2×2 arrayed MLA element, driven by a 4-phase voltage (sine, cosine, -sine and -cosine). They fabricated monolithic 2×2 arrayed elements with the size $2.6\times 2.6\times 1.1$ mm³ including buffers with layer thickness as thin as 18 μm [Refer to Figure 8(b) and (c)]. Because of this layer thinness and dramatic enhancement in the piezoelectric performance owing to the magnetic field alignment, the ultrasonic motor was successfully driven under only 3 V_{p-p}, which is low enough to be adopted in mobile phones without coupling a step-up drive circuit.

Refer to a review paper on Pb-free piezoelectrics by T. Tsurumi [13]. Though their piezoelectric performance is not superior to the PZTs, commercialization efforts have been already made, which were introduced in the above paragraphs.

Figure 8: (a) Compact rotary ultrasonic motor with a piezoelectric multilayer actuator, (b) 2×2 arrayed element, and (c) cross-section view of the 18 μm -layer ML element [12].

Disposal Technology of Hazardous Materials

Ultrasonic lens cleaner is commonly used in homes. Industrial ultrasonic cleaners are widely utilized in the manufacturing lines of Silicon wafers and liquid crystal display glass substrates. With increasing the ultrasonic power level in water, cavitation (vacuum particle) is generated in water. Because the cavitation (cyclic adiabatic compression at around 28 kHz) generates more than 3,000°C micro-locally for a short period, we can make hazardous waste innocuous. Various hazardous wastes can be found underground or in sewer water, including dioxin, trichloroethylene, PCB, environmental hormone etc., which have been produced in the late 20th century. It is well known that dioxin becomes another toxic material when it is burned at a low temperature in typical garbage disposal furnaces, while it becomes innocuous only when burned at a high enough temperature. Ultrasonic irradiation is highly prospected for this application. Since the chemical reaction is induced in water (i.e., so-called sono-chemistry), dioxin can be dissolved into innocuous materials without increasing temperature apparently.

Honda Electronics added an ultrasonic stain remover in a washing machine produced by Sharp. Figure 9 shows their L-L coupler horn to generate water cavitation for removing oily dirt from a shirt collar. It is noteworthy that we can reduce the amount of detergent (which is one of the major causes of the river contamination) significantly by this technique.

Reduction of Contamination Gas

Diesel engines are recommended rather than regular gasoline cars from the energy conservation and global warming viewpoint. Why? We need to consider the total energy of gasoline production; well-to-tank and tank-to-wheel. The energy efficiency, measured by the total energy required to realize unit drive distance for a vehicle (MJ/km), is of course better for high octane gasoline than diesel oil. However, since the electric energy required for purification is significant, the gasoline is inferior to diesel. As well known, the conventional diesel engine, however, generates toxic exhaust gases such as SO_x and NO_x . In order to solve this problem, new diesel injection valves were developed by Siemens, Bosch and Toyota with piezoelectric ML actuators. Figure 10 shows a common rail type diesel injection valve [14].

In order to eliminate toxic SO_x and NO_x and increase the diesel engine efficiency, high pressure fuel and quick injection control are required. The highest reliability of these devices at an elevated temperature (150°C) for a long period (10 years) has been achieved [14]. Note that the piezoelectric actuator is a key component to increase the burning efficiency and minimize the toxic exhaust gas elements.

New Energy Harvesting Systems

One of the most recent research interests is piezoelectric energy harvesting. Cyclic electric field excited in the piezoelectric plate by the environmental noise vibration is now accumulated into a rechargeable battery without consuming it as Joule heat. NEC-Tokin developed an LED traffic light array system driven by a piezoelectric windmill, which is operated by wind generated

effectively by passing automobiles. Successful products (million sellers) in the commercial market include “Lightning Switch” (remote switch for room lights, with using a unimorph piezoelectric component) by Pulse Switch Systems, VA [15]. In addition to the living convenience, *Lightning Switch* (Figure 11) can reduce the housing construction cost drastically, due to a significant reduction of the copper electric wire and the aligning labor.

The Penn State group developed energy harvesting piezoelectric devices based on a “Cymbal” structure (29 mmφ, 1-2 mm thick), which can generate electric energy up to 100 mW under an automobile engine vibration [16-18]. By combining 3

Figure 9: L-L coupler horn for a washing machine application. [Courtesy by Honda Electronics].

Figure 10: Common rail type diesel injection valve with a piezoelectric multilayer actuator. [Courtesy by Denso Corporation].

Figure 11: Lightning Switch with piezoelectric Thunder actuator. [Courtesy by Face Electronics].

cymbals in a rubber composite, a washer-like energy harvesting sheet was developed for a hybrid car application, aiming at 1 W constant accumulation to a fuel cell.

Crisis Technology

In my proposition, Politico-Engineering covers (1) legally-regulated normal technologies such as sustainability [discussed in the previous section], and (2) crisis technologies. Further, there are five types of “crises”:

1. Natural disasters (earthquakes, tsunamis, tornadoes, hurricanes, lightning, etc.),
2. Epidemic/infectious diseases (smallpox, polio, measles, and HIV),
3. Enormous accident (Three-Mile-Island core meltdown accident, BP oil spill etc.),
4. Intentional accidents (acts of terrorism, criminal activity, etc.),
5. Civil-war, war, territorial aggression.

As infectious or contagious disease involves some association with terrorist activities, those five are related to each other. In the United States, politicians were attacked with anthrax in 2001. **Disaster** is what happens in the accident, and it is not intentionally caused. **Crisis** contains all those intentionally cause or accidentally happen.

Natural Disaster

The research effort into crisis engineering will be highly required for natural disasters. The research themes of urgent need in the actuator/sensor area are the following:

- (1) Accurate monitoring and surveillance techniques (e.g., vibration and pressure sensors) for an earthquake, tsunami, typhoon, or tornado;
- (2) Technologies for gathering and managing crisis information and informing the public (e.g., directive loud speakers) in a way not to bring about panic reaction;
- (3) Rescue technologies (autonomous unmanned underwater, aerial, land vehicles, robots, etc.).

Epidemic/Infectious Disease

Quartz is used for various micro-mass sensors. Because the mechanical quality factor Q_m is very large ($\sim 10^6$), the monitoring resolution of the resonance frequency reaches $\Delta f_R/f_R \sim 10^{-6}$. Thus, even small mass change on the quartz surface can be finely detected through the resonance frequency shift. This micro mass sensor can be utilized as a bio-sensor for detecting bacteria, such as E. coli and Salmonella. $10^4 \sim 10^7$ cells per ml is already critical to humans for Salmonella's case. A specific antibody/phage is coated on a single crystal quartz oscillator. Once particular bacteria are captured selectively by the antibodies, the surface mass of the oscillator is increased. A sensitivity of 10^4 cells per ml has been reported [19].

On the other hand, in order to neutralize the biological attack, Pezeshk et al. at The Penn State University developed a portable hypochlorous-acid disinfection device with using a piezoelectric ultrasonic humidifier [20]. Hypochlorous Acid has proven to be a strong disinfectant with no side effects on humans and would be ideal for disinfection of office and hospital buildings against viruses like SARS, Anthrax, etc. Coupled with the atomization of the acidic solution, much higher disinfection effects can be expected. The acid is not sold as a pure solution since it naturally disintegrates after a few hours. A corrosion resistant electrolytic cell was designed to produce hypochlorous acid from brine. Nafion® membranes were used to separate the anode and cathode compartments and produce hypochlorous acid and sodium hydroxide in the anode and cathode compartments, respectively. An ultrasonic piezoelectric atomizer was utilized to generate micro-droplets of the diluted acid.

Figure 12 shows the general configuration of the electrolytic cell. The membrane in the cell is permeable to many cations and polar compounds but can almost completely reject anions and nonpolar species. Therefore, Sodium ions will be trapped in the cathode compartment preventing them from reacting with the OCl^- ions to produce NaOCl , which is not as strong a disinfectant as HOCl .

Enormous Accident

As described in Introduction, the Fukushima Daiichi nuclear power plant “melt-down” occurred as a result of the earthquake/tsunami, followed by explosion.

Because the explosion happened owing to lack of the monitoring system of the melt-down, Tittmann et al. at The Penn State are developing a high temperature (600°C) piezo-electric transducer with an AlN single crystal for monitoring the uranium rod condition in a nuclear chamber, as shown in Figure 13 [21].

Intentional Accident/War

Until 1960s, the development of *weapons of mass destruction* (WMD) was the primary focus, including nuclear bombs and chemical weapons. However, based on the global trend for “Jus in Bello (Justice in War)”, *environment-friendly “green” weapons* became the main-stream in the 21st century; that is, minimal destructive weapons with a pin-point target such as laser guns

Figure 12: Generation of Chlorine and Caustic in a membrane electrolytic cell [20].

Figure 13: AlN piezoelectric transducer for monitoring the uranium rod condition in a nuclear chamber [21].

Figure 14: Difference among the product planning strategies for techno-, econo-, and politico-engineering.

and rail guns. In this direction, programmable air-burst munition (PABM) was developed successfully from 2004. The 25 mm caliber “Programmable Ammunition” by ATK Integrated Weapon Systems, AZ and Micromechatronics, PA [22]. Instead of a battery, a multilayer piezo-actuator is used for generating electric energy under shot impact to activate the operational amplifiers which ignite the burst according to the command program.

Summary

The first quarter of 21st century seems to be the age of “Politico-Engineering”; that is, strong political initiative is

required for promoting the engineering development. The paradigm shift from econo-engineering to politico-engineering is mandatory in Science & Technology development. In 1980s, i.e., “Bubble Economy” period, cost/performance technologies were sought, while in these 20 years, **sustainability and crisis technologies** should be the mainstream. The crisis includes (1) natural disaster (earthquake, tsunami, tornado, typhoon, thunder), (2) infectious/contagious disease (smallpox, poliomyelitis, measles, HIV), (3) enormous accident (Three-mile-island nuclear power plant melt-down, BP deep-water oil flow), (4) intentional (terrorist/criminal) incident, and (5) external & civil war/territorial invasion.

The sustainability technologies in the piezoelectric device area include (a) development of **non-toxic piezo-materials**, (b) **disposal technology** for existing hazardous materials with using ultrasonic cavitation, (c) **reduction of contamination gas** with piezo-devices, (d) new **energy source creation** (i.e., piezoelectric energy harvesting), and (e) **energy-efficient piezoelectric device** development. Urgent necessity to the crisis technologies can be found in the following sensors and actuators:

- (a) Accurate monitoring and surveillance techniques (e.g., vibration and pressure sensors) for an earthquake, tsunami, typhoon, or tornado.
- (b) Rescue technologies such as autonomous unmanned underwater, aerial, land vehicles, robots, with compact and high energy-density actuators.
- (c) Detection and neutralization technologies of epidemic/infectious disease.
- (d) Nuclear power plant monitoring technologies such as high temperature (600°C) piezoelectric sensors for monitoring the uranium rod condition.
- (e) Minimal destructive weapons with a pin-point target such as laser guns and rail guns.
- (f) Small energy sources for remote actuating/ sensing systems and high voltage supplies with piezoelectric transformers are highly focused in the politico-engineering period.

This paper proposed a new four-Chinese-character keyword for the era of “politico-engineering”, “*cooperation, protection, reduction, and continuation*”. Global coordination and international cooperation in standardization of internet systems and computer cables became essential to accelerate the mutual communication. The “Kyoto Protocol” is an international agreement linked to the United Nations Framework Convention on Climate Change. *Protection* of the territory and environment from the enemy or natural disaster, and of infectious disease spread is mandatory. *Reduction* of toxic materials such as lead, heavy metals, dioxin, and of the use of resources and energy consumption is also the key, and the society continuation, i.e., *status quo* or *Sustainable Society*, is important to promote. Note that the author proposed in the previous Actuator 2010 [23] a four-Chinese-character slogan for the 21st century; that is, “beautiful, amusing, tasteful,

and creative”. Though I still believe this will come in the future, “cooperation, protection, reduction, and continuation” seems to be the immediate slogan in these 10~15 years until our global recovery in both political and economical aspects.

Finally, we compare the difference among the product planning strategies for techno-, econo-, and politico-engineering. As illustrated in Figure 14, in the techno-engineering (exemplified by single crystal relaxor piezoelectrics), the fundamental science and technology (S&T) or the discovery comes first as the key, then followed by the development, and finally application products are created. In the econo-engineering (exemplified by piezo-multilayer components), the final product specs, in particular, in mass-production capability and manufacturing cost, come first. Based on these desired specs, manufacturing processes are developed as the key. To the contrary, in the politico-engineering (exemplified by Pb-free piezoelectrics), the legal regulation for the final products comes first with strict constraints in terms of law-issuing date, performance regulation (e.g., Pb fraction in the final product, CO₂, NO_x, or SO_x emission amount, specifications for rescue robots, new weapons). In the case of the automobile diesel injection valve, the multilayer actuator development was the key for providing the solution; while in the RoHS regulation on the PZT, we need to discover and develop new Pb-free piezoelectric materials.

The most important issue in the politico-engineering age is the leading politicians’ action/motion on how to protect the domestic industries against the foreign pressure. Taking into account the current domestic S&T capabilities, with intimate collaboration with the leading domestic politicians, the global regulation needs to be accepted. In other words, the engineers need to instruct the leading politicians on the correct up-to-date technologies. Otherwise, the domestic industrial crush may happen. One of the typical items can be found in the power generation with nuclear power. Depending on the country’s alternative energy generation capability, the electric blackout and industrial bankruptcy will happen, if the nuclear power plant would be shut down so soon just by considering general fear against the nuclear power. The key is to develop the safety/security systems for the nuclear power plants even under a crisis situation before deciding to remove them without alternative energy source.

References

1. http://en.wikipedia.org/wiki/Galileo_Galilei
2. http://en.wikipedia.org/wiki/Benjamin_Franklin#Early_life (as of March, 2008)
3. http://en.wikipedia.org/wiki/James_Watt
4. Uchino, K., (2010). *Advanced Piezoelectric Materials*. UK: Woodhead Publishing.
5. Honda, K., (1994). *Ultrasonic World*. Japan: NHK books.
6. Sawaguchi, E. (1953). Ferroelectricity versus anti-ferroelectricity in the solid solutions of PbZrO₃ and PbTiO₃. *Journal of the Physical Society of Japan*, **8**, 615–629.
7. http://unfccc.int/kyoto_protocol/items/2830.php

8. Kuwata, J., Uchino, K., & Nomura, S. (1982). Dielectric and piezoelectric properties of $0.91\text{pb}(\text{zn}_{1/3}\text{nb}_{2/3})\text{o}_3\text{-}0.09\text{pbtio}_3$ single crystals. *Japanese Journal of Applied Physics*, 21, 1298–1302.
9. Uchino, K., Zhuang, Y., & Ural, S. O. (2011). Loss determination methodology for a piezoelectric ceramic: new phenomenological theory and experimental proposals. *Journal of Advanced Dielectrics*, 1(1), 17–31.
10. Tou, T., Hamaguchi, Y., Maida, Y., Yamamori, H., Takahashi, K., & Terashima, Y. (2009). *Journal of Applied Physics*, 48, 07GM03.
11. Y. Saito (1996), Measurement system for electric field-induced strain by use of displacement magnification technique. *Japanese Journal of Applied Physics*, 35, 5168–2173.
12. Y. Doshida, Proc. 81st Smart Actuators/Sensors Study Committee, JTAS, Dec. 11, Tokyo (2009)
13. Tsurumi, T. (2005), *Journal of the Ceramic Society of Japan*, p. 40.
14. A. Fujii, Proc. Smart Actuators/Sensors Study Committee, JTAS, Dec. 2, Tokyo (2005)
15. <http://www.lightningswitch.com/>
16. Kim H. –W., Priya S., Uchino, K., & Newnham, R. E. (2005). Piezoelectric energy harvesting under high pre-stressed cyclic vibrations. *Journal of Electroceramics*, 15(1), 27–34.
17. Kim, H. –W., Uchino, K., & Daue, T. (2005). Proc. CD 9th Japan International SAMPE Symp. & Exhibition, SIT Session 05, Nov. 29th–Dec. 2nd.
18. Kim, H. –W., Priya, S., & Uchino, K. (2006). Modeling of piezoelectric energy harvesting using cymbal transducers. *Journal of Applied Physics*, 45, 5836–5840.
19. Cheng, Z. –Y. (2003) Private Communication, Auburn University.
20. Pezeshk, A., Gao, Y. & Uchino, K. (2004). Ultrasonic Piezoelectric Hypochlorous Acid Humidifier for Disinfection Applications. *NSF EE REU Penn State Annual Research Journal*, 2.
21. Tittmann, B. R. (2011). Proc. ICAT 62nd International Smart Actuator Symposium, State College, PA, Oct 4–5.
22. http://www.atk.com/MediaCenter/mediacenter_video_gallery.asp
23. Uchino, K. (2010). Proc. New Actuator 2010, A3.0, Bremen, Germany, June 14–16.