The Electricity Generation System Based on Piezoelectric Ceramic Applying on Road Deceleration Strip

Applicants：Shi Rui, Huang Lixiao, Yang Chenxiao
Supervisor：Li Zhou
School: Southeast University

Contents

Abstract

Nowadays, using the road deceleration strips to announce vehicles to decrease its speed are very common. Due to the decrease of the speed, we can find that the road with deceleration strips usually has more traffic. Moreover, according to our research, we found that a normal sedan owes a weight of 1 to 2 tons. By effectively using the high speed and great weight of the motor vehicle, we can convert the unwanted kinetic energy into useful electricity through out electricity generation system. In this system, we use piezoelectric ceramic as main material to produce energy. The piezoelectric ceramic has the ability to exchange deformation into electricity and the bigger the pressure and deformation, the more energy the material could produce, which perfectly match the specialties of the road deceleration strips. When the vehicle passes through the strip, the strip will deliver the pressure and deformation to the piezoelectric ceramics which are installed inside the strips. After that, the energy collecting circuits will store the electricity to the accumulator in high efficiency. Moreover, this system also can be used in different situation such as the subway rail ,which also works by using the high weight and velocity. This system successfully achieved the target of converting the wasted energy to useful electricity, so that this design perfectly match with the aim of this competition。

Key Words：piezoelectric patches, electricity generation, Road Deceleration Strip, pressure, energy collecting circuit

Authors Information:

Name: Shi Rui, Huang Lixiao, Yang Chenxiao
Degree: bachelor
Affiliation: Southeast University
Address: Jiu Longhu Compus of Southeast University, Nanjing, China
Phone Number: 15651769852, 18509080326, 18795886812
E-mail Address: 672800554@qq.com

1 The Background and Significant of the Design

1.1 The Background of the Piezoelectric Effect

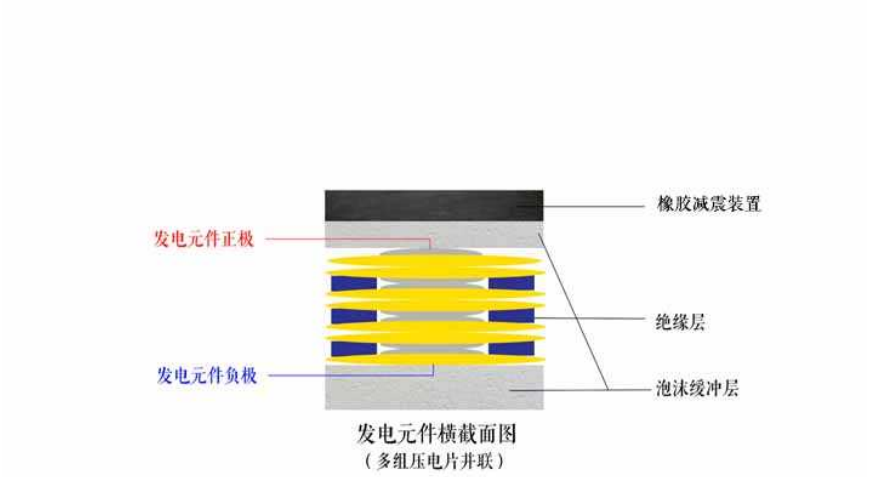
The piezoelectric effect is understood as the linear electromechanical interaction between the mechanical and the electrical state in crystalline materials with no inversion symmetry. The piezoelectric effect is a reversible process in that materials exhibiting the direct piezoelectric effect (the internal generation of electrical charge resulting from an applied mechanical force) also exhibit the reverse piezoelectric effect (the internal generation of a mechanical strain resulting from an applied electrical field). For example, lead zirconate titanate crystals will generate measurable piezoelectricity when their static structure is deformed by about 0.1% of the original dimension. Conversely, those same crystals will change about 0.1% of their static dimension when an external electric field is applied to the material. The inverse piezoelectric effect is used in production of ultrasonic sound waves.

2 Designing Scheme

2.1 The Reason for Design

在日常生活中，汽车具有很强的舒适性、便捷性，因此是目前非常普遍的交通工具。并且，汽车在通过道路减速带时，将消耗大量动能，在平常这部分能量没有被利用，而我们通过对减速带的改造，在其内部安装压电模块利用其重力及形变产生电量，从而将这部分能量收集起来，实现节能减排的目的。

2.2 The Construction Drawing of Electricity Generation Module



（1） The Construction Drawing of Electricity Generation Module

The construction drawing of electricity generation module is as shown in the figure

(1), it is constituted by hard rubber and vesicle layer which act as buffer to protect the module from damage, piezoelectric plates which work to generate electricity and insulation layer which prevent negative poles of two piezoelectric plates from connecting and make sure all the piezoelectric plates are connected in parallel. The electricity generation module are wrapped by hard rubber and vesicle layer, when there is pressure act on electricity generation device, the power and deformation will be delivered by hard rubber and vesicle layer, which greatly protect the piezoelectric plates from damage and increase the working life of the module. The big pressure act on electricity generation module can shorten the distance of galvanic couple within the piezoelectric plates. To resist the change, this material can produce positive and negative electric charges on the surface of the piezoelectric plates. This procedure achieves the transformation from mechanical energy to electricity, after that, the electricity produced by this module will be collected with high efficient into batteries through energy collecting circuit.

The hard rubber can suffer high pressure and also have capacity returning to a previous shape after deformation. Thus, this material is widely used on large machinery, such as crane, bulldozer and so on. In this device, we use hard rubber as buffer to protect electricity generation module, control the pressure module suffers and decrease the choppy.

2.3 The Practical Use of the Electricity Generation System

Considering that the piezoelectric plates need discontinuous pressure to produce electricity, and according to our research, nowadays road deceleration strip is installed separately, the black and yellow rubber pieces are not disjointed. Thus, each time the vehicle passes through the strip, only the rubber piece which directly pressed by the vehicle can delivered the pressure and deformation to the electricity generation module under it, and the press can not be delivered to other pieces, which will lead to the decrease of proficiency. So that, we changed the design of the normal strip, and make sure that whatever which price gets pressure, the force can be delivered to other pieces.

（2） Road deceleration trip

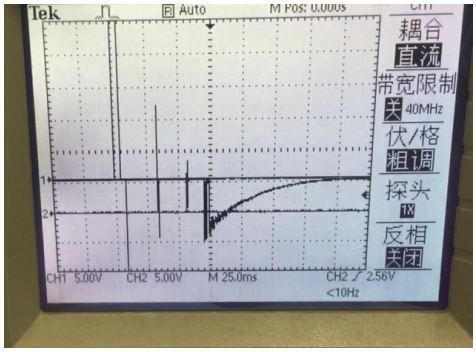
2.4 The Design of Circuit

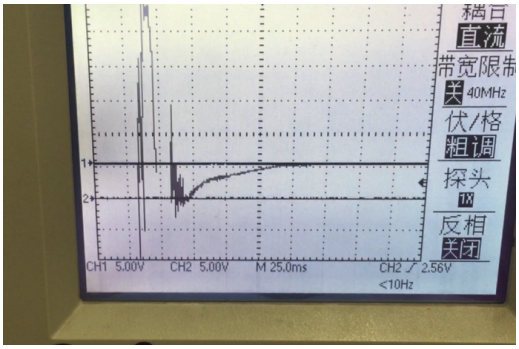
2.4.1 The Voltage Curves Produced by Series and Parallel

Connection of Piezoelectric Plate

1. The Voltage Curves Produced by single Piezoelectric Plate

In the experiment, we connected single piezoelectric plate with oscilloscope, and press the plate in certain frequency and force. Through observing the voltage curve showed by the oscilloscope, we found that: The transient voltage spike was high, however the value was not stable and the spike on last for very short time; The value of current is low but stable due to the high internal resistance of piezoelectric plate.

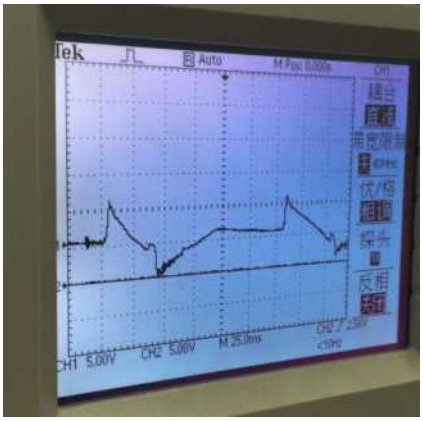


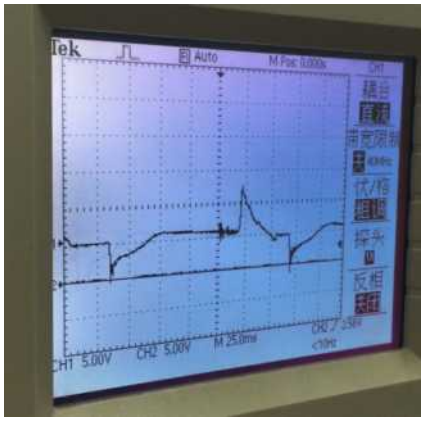


（3） The Voltage Curves Produced by single Piezoelectric Plate

2. The Voltage Curves Produced by Series Connection of Two Piezoelectric Plates

According to basic physic knowledge, when we connect two piezoelectric plates in series, the internal resistance will increase and the voltage will be more stable. In the experiment, we connected two piezoelectric plates in serious, linked them with oscilloscope, and press the plate in certain frequency and force. Through observing the voltage curve showed by the oscilloscope, we found that: The transient voltage spike decreased but became more stable; the value of current did not change but become more stable.



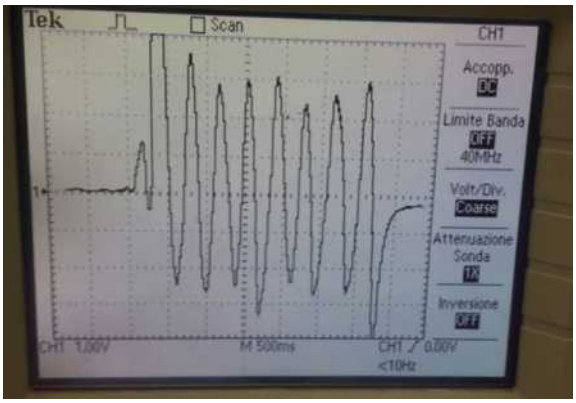


（4） The Voltage Curves Produced by Series Connection of Two Piezoelectric Plates

3. The Voltage Curves Produced by Parallel Connection of Two Piezoelectric Plates

According to basic physic knowledge, when we connect two piezoelectric plates in parallel, the internal resistance will decrease greatly and the voltage will be more stable. In the experiment, we connected two piezoelectric plates in parallel, linked them with oscilloscope, and press the plate in certain frequency and force. Through observing the voltage curve showed by the oscilloscope, we found that: The transient voltage spike did not increase but became more stable and the voltage curve showed that it became standard alternating current; the value of current increased greatly compared with serious connection due to the decrease of internal resistance.

Overall, we discovered that to achieve the best energy collecting effect, we should use the parallel connection to connect all piezoelectric plates. Through this method, we can to a large extent increase the value of voltage and current.

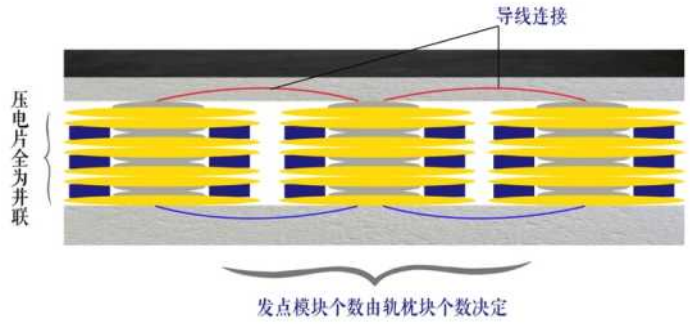


（5） The Voltage Curves Produced by Parallel Connection of Fifty Piezoelectric Plate

We connected 50 piezoelectric plates in parallel. Through observing the voltage curve showed by the oscilloscope, we found that: Comparing to the parallel connection of two, the voltage of 50 had higher frequency and peak value.

This experiment showed that through parallel connection, we could make the output voltage become standard alternating current with high frequency and peak value.

2.4.2 The Module Design



（6） The Whole Module design drawing

We organized groups of electricity generation modules in to line (every module has same amount of piezoelectric plates) and connected them in parallel. Through this design, we achieved these targets:

1. All the piezoelectric plates are connected in parallel, so that the internal resistance could be dramatically decreased which makes sure the current is high enough to be stored in the accumulators.
2. When there is pressure acting on the hard rubber, this design can make sure all piezoelectric plates in one module suffer the same pressure and deformation, which assures the stable of output current and prolong the duration time.

3 The Value of Practical Measurements and Estimate

3.1 Piezoelectric Effects

3.1.1 The Definition of Piezoelectric Effects

The nature of the piezoelectric effect is closely related to the occurrence of electric dipole moments in solids. The latter may either be induced for ions on crystal lattice sites with asymmetric charge surroundings (as in BaTiO3 and PZTs) or may directly be carried by molecular groups (as in cane sugar). The dipole density or polarization (dimensionality [Cm/m3]) may easily be calculated for crystals by summing up the dipole moments per volume of the crystallographic unit cell. As every dipole is a vector, the dipole density P is a vector field. Dipoles near each other tend to be aligned in regions called Weiss domains. The domains are usually randomly oriented, but can be aligned using the process of poling (not the same as magnetic polling), a process by which a strong electric field is applied across the material, usually at elevated temperatures. Not all piezoelectric materials can be poled.

3.1.2 The Equation Set of Piezoelectric Effects

Piezoelectricity is the combined effect of the electrical behavior of the material:

$$\mathbf{D} = \boldsymbol{\varepsilon}\,\mathbf{E} \quad \Longrightarrow \quad D_i = \varepsilon_{ij}\,E_j$$

Where D is the electric charge density displacement (electric displacement), ε is permittivity and E is electric field strength, and Hooke's Law:

$$\boldsymbol{S} = \mathsf{s}\,\boldsymbol{T} \quad \Longrightarrow \quad S_{ij} = s_{ijkl}\,T_{kl}$$

Where S is strain, s is compliance and T is stress.

These may be combined into so-called coupled equations, of which the strain-charge form is:

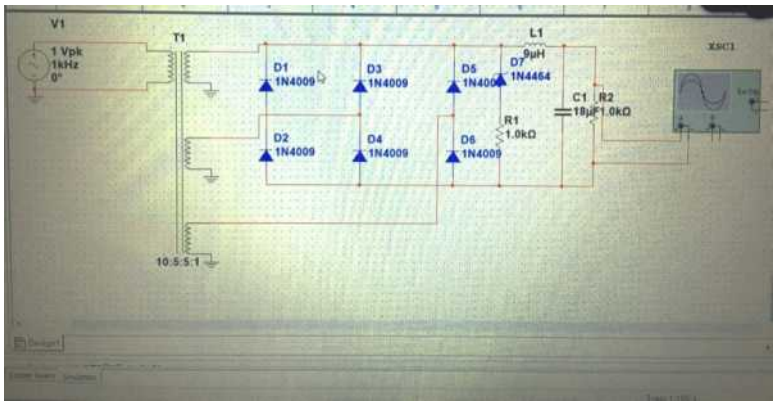
$$\boldsymbol{S} = \mathsf{s}\,\boldsymbol{T} + \mathfrak{d}^t\,\mathbf{E} \quad \Longrightarrow \quad S_{ij} = s_{ijkl}\,T_{kl} + d_{kij}\,E_k$$
$$\mathbf{D} = \mathfrak{d}\,\boldsymbol{T} + \boldsymbol{\varepsilon}\,\mathbf{E} \quad \Longrightarrow \quad D_i = d_{ijk}\,T_{jk} + \varepsilon_{ij}\,E_j\,.$$

$$\{S\} = \left[s^E\right]\{T\} + [d^t]\{E\}$$
$$\{D\} = [d]\{T\} + \left[\varepsilon^T\right]\{E\}\,,$$

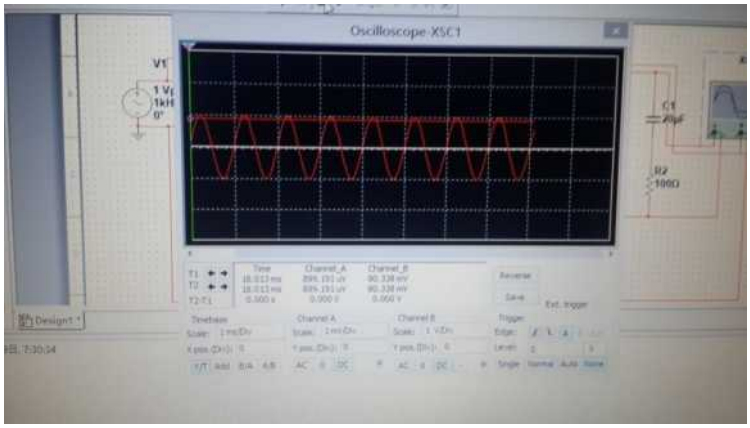
In matrix form, where $[d]$ is the matrix for the direct piezoelectric effect and $[d^t]$ is the matrix for the converse piezoelectric effect. The superscript E indicates a zero, or constant, electric field; the superscript T indicates a zero, or constant, stress field; and the superscript t stands for transposition of a matrix.

3.2 Electric Circuits of Rectifier and Filter & The Value of Practical Measurements and Estimate

In alternating current (AC), the flow of electric charge periodically reverses direction, whereas in direct current (DC, also dc), the flow of electric charge is only in one direction. To achieve the final target that storing the electricity generated by modules in accumulator, we should deform the alternating current into direct current with the help of rectifier and filter circuits. A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. The process is known as rectification. Electronic filters are analog circuits which perform signal processing functions, specifically to remove unwanted frequency components from the signal, to enhance wanted ones, or both. In the end, we use voltage-regulator diode to firm the value of voltage.



（7） Electric circuits of rectifier and filter



（8） The Voltage Waveform Output by Simulation Software

Through electric circuit of rectifier and filter, we achieved the high efficiency transformation from alternating current to direct current which can be restored in batteries directly.

3.3 The Value of Practical Measurements

Experiment to one electricity generation module(contains 50 piezoelectric plates), push with the power of 50N（about twice per seconds）, we got：

Current：15mA

Voltage：4V

Resistance：0.266kΩ

3.4 Calculation procedure (simulating practical situation)

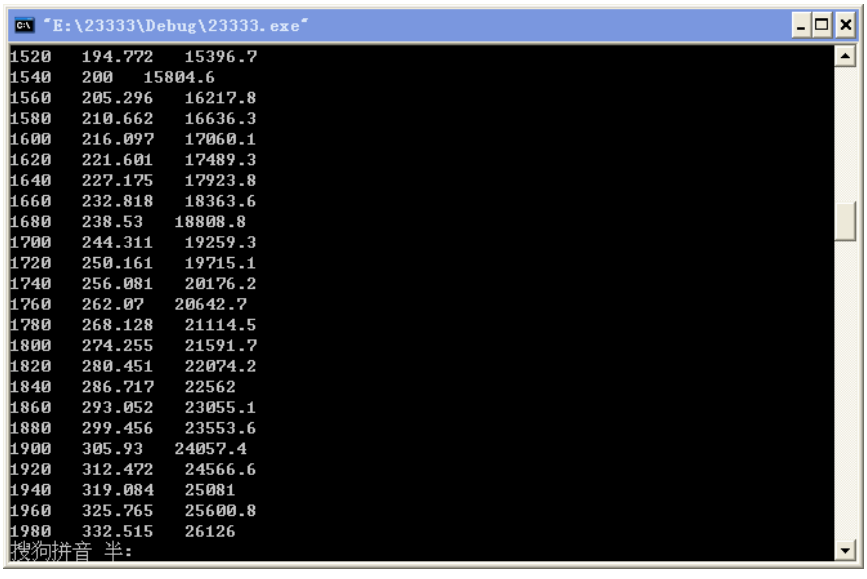
The image (9) shows the calculation procedure of simulating practical situation. We inputted all the related parameter of piezoelectric plates and the frequency of press and get all the estimating generated power correlated to different stress value (the value range from 10N to 4000N)

```
#include<fstream.h>
#include<iostream.h>
#include<math.h>
#define PI 3.14;
void main()
{
    double a,u,c,v,w,r,e,E,f,S,P,T,R;
    cout<<"a=";
        cin>>a;
        cout<<"c=";
        cin>>c;
        cout<<"v=";
        cin>>v;
        cout<<"w=";
        cin>>w;
        cout<<"r=";
        cin>>r;
        cout<<"e=";
        cin>>e;
        cout<<"E=";
        cin>>E;
    cout<<"R=";
        cin>>R;
        cout<<"f=";
        cin>>f;
    fstream outfile("e:\\test\\data.txt",ios::out);
        double b[1000][2];
        for(int i=0;i<100;i++)
        {
                T=i*20;
                b[i][1]=P;
                b[i][0]=T;
                S=T/765000;
                u=e*E+16.7*T;
                P=pow(2*a*(u*(r/(r+R ))-4*c*v,2)*pow(w,2)*r/pow(2*r*c*w+3.14,2);
                double n=0.5*7800*pow(S*1000,2);
                cout<<b[i][0]<<"    "<<b[i][1]<<"    "<<n<<'\n';
                outfile<<b[i][0]<<" "<<b[i][1]<<'\n';
        }
        outfile.close();

}
```

（9） Calculation procedure

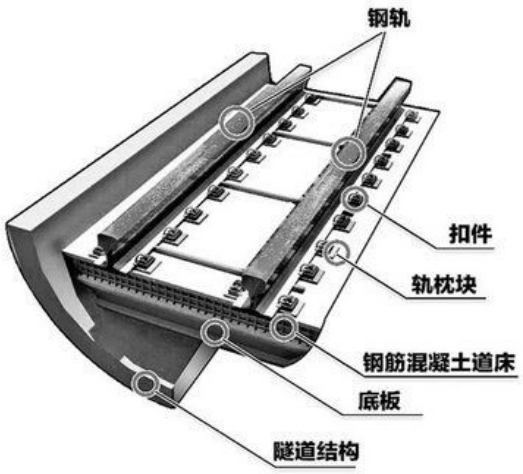
The image (10) is the computational results of the calculation procedure. The first row is the estimate pressure acts on the module, the second row is the generated power, and the third row is the kinetic energy that the motor vehicle would loss when it pass through the declaration stripe.



（10） Computational results（1000N－2000N）

According to the output of the computational results, we found that if the pressure is controlled around the value of 1980N, one electricity generation module (constitute by 200 piezoelectric plates) could produce 0.002 KWh. Through our research towards the standard road deceleration strip, the strips' length are determined by the practical length of the road, and normally longer than 6 meters, so that each strip can at least install 100 row electricity generation module (each plates' diameter is 40mm). The width is range from 300mm±5mm to 400mm±5mm, so that each strip can at least install 5-8 row. After calculating, we got that the whole system can generate **1KWh** when one motor vehicle passed through the strip.

4 The Other Use of the Electricity Generation System



（11） The subway rail

In our daily life, taking subway is a very common way to travel. If we pay attention to the subway itself, it will be easy for us to notice that the cars of the subway have tremendous amount of weight and have great speed at run time. According to our research, we recognized that one car of the subway without passenger on it can reach a weight of 36 to 38 ton. Also, when it run to the smooth running section, its speed can achieve 80km/h. Since, the subway has tremendous weight and great speed at run time, which can be fully used by piezoelectric ceramic: the piezoelectric ceramic produce electronic through being continually pressed in high frequency, and the higher the pressure and the frequency, the more electronic it can generate, we designed a electrical power generating system by using the piezoelectric ceramic as the electricity generating part and put it under the rail. When the subway pass through the certain part of the rail, piezoelectric ceramics which are asserted under each sleeper would be compressed continually, then the electric current would pass through the circuits which can make the current more steadily, and finally being collected by electronic or being used by the car of the subway directly. Using this electronic system, we can truly achieve the objective of the energy saving.

However, because of the tremendous weight of the subway, we have not found a proper way to protect the piezoelectric plates from undertaking such great pressure, so that the pressure might damage the plates. If this problem can be solved, this system can install under the subway rail and bring tremendous electricity.

5 Innovation points

1）Piezoelectric ceramics are very cheap but can generate big amount of electricity, by using this material, we can achieve the objective of low cost and high-efficiency.

2） There is no need for worker to operate it, the electricity can be collected by battery automatic when the vehicle passing through the strip.

3) Nowadays, the using of road deceleration strips are very common, thus, if this system can be achieved successfully, it can be applied on different places and collect the energy that used to be wasted.

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