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Generation of Electrical Energy From Blast Induced Vibrations

Raghu Chandra Garimella*, Rama Sastry Vedala
Department of Mining Engineering, National Institute of Technology Karnataka, Surathkal, India

ABSTRACT

Generation of electrical energy has become a basic aspect in power system because of incremental demands from citizenry in electrical distribution system. Power may be generated in different ways. Numerous developments took place in power generation technology for the generation of electricity, but those are all dependent on conventional sources. In the present research, generation of electrical energy using piezo sensors was done by tapping electrical voltage from undesirable ground vibrations generated from blasts in mines.

Blasting operations in mines and quarries always result in ground vibrations, which are of major environmental concern, to be investigated by the researchers. Studies were carried out in three different limestone mines and two different sandstone bench formations of coal mines, situated in Southern India, to assess and analyze the seismic energy resulting from the blast induced ground vibrations. In total, 116 blast vibration events in limestone formation and 94 blast vibration events in sandstone formation were studied from various blasts. It was observed that there is a potential for tapping of electrical energy from the ground vibrations generated due to blasts carried out in mines and quarries, using piezo sensors. Piezo generator circuits were developed and used in addition to the seismographs at different distances ranging from the short to long range in all mining locations, to tap the ground vibrations. Electrical voltage was tapped from the blast induced ground vibrations during studies, which later was used for running low powered VLSI systems as ambient power source. Also, it was noticed that the obtained electrical potential is in direct proportion to the input vibration intensity.

The range of voltage tapped from ground vibrations is up to 4531.42mV in limestone and 4277.51mV in sandstone formations. Further, the amount of voltage acquired was used to obtain the intensity of blast vibrations. A very good correlation between seismic energy (obtained from ground vibrations using signal processing analysis) and electrical energy (obtained from piezo generator developed) was observed during the studies, i.e. about 99% in both formations. Results also indicated that the working of piezo sensor in tapping ground vibrations is as accurate as traditional ground vibration monitors.

Keywords: electricity generation, piezo generator, seismograph, seismic energy, signal processing

*Corresponding Author
E-mail: raghuchandhra@gmail.com

INTRODUCTION

When the charge detonates in a blasthole under confinement, the chemical energy of the explosive is converted into heat and works to the surroundings with an enormous pressure according to the first principle of thermodynamics (Johansson and Persson [1]). Explosion of a spherical charge in an infinite rock medium results in three major zones: (1) Explosion cavity, where explosion energy is liberated and the process is hydrodynamic; (2) Transition

zone, where plastic flow, crushing and cracking occur; and (3) seismic zone, where strain waves travel as seismic waves (Atchison et al. [2]; Nicholls [3]; Sastry [4]).

The partition of the explosive energy in a blast depends on the end effects involved. For instance, part of the fracture work is in its first stage intimately connected to the shock wave flow in the locality of the hole and, in the later stages, also to the rock movement, which begins as the fractures burst open. All other energy transfer takes place obviously, as follows: (a) expansion work of the fractures, that is absorbed as elastic and plastic deformation of the rock in the surface of fractures as they are penetrated by the gases; (b) heat transferred to the rock from the hot detonation products; and (c) heat and work conveyed as enthalpy of the gases venting to the atmosphere through open fractures and stemming (Sanchidria´n et al. [5]).

Seismographs, high-speed video camera and fragmentation monitoring systems were used to measure the seismic field, the initial velocity of the blasted rock face and the fragment size distribution curve, respectively, from which the various energy terms are calculated.

PIEZO-GEN TECHNIQUE

Piezoelectricity is a phenomenon of electricity assembled in some solid materials (such as crystalline particles, certain ceramic substances, and biological composition for example bone, DNA and various proteins) due to applied mechanical stress. The electricity resulting from applied pressure is known as piezoelectricity. The word "piezo" derived from the Greek "piezein", means to squeeze or press, and "electric" or "electron", derived from "amber", which is an ancient source of electric charge. Piezoelectricity was discovered in 1880 by French physicists Jacques and Pierre Curie (Anon [6]; Jacques and Curie [7]; Tingley [8]).

Piezoelectricity is the ability of some materials such as crystals and certain ceramics, to generate an electric potential in response to applied mechanical stress or heat (Jacques and Curie [7]; Pramethesth and Ankur [9]). However, piezoelectricity is not caused by a change in charge density on the surface, but by dipole density in the bulk. For example, a 1 cm^3 cube of quartz with 2kN of correctly applied force can produce a voltage of 12500 V (Jacques and Curie [10]). Mechanical compression or tension on a poled piezoelectric ceramic element changes the dipole moment, creating a voltage. Compression along the direction of polarization, or tension perpendicular to the direction of polarization, generates voltage of the same polarity as the poling voltage (Figure 1).
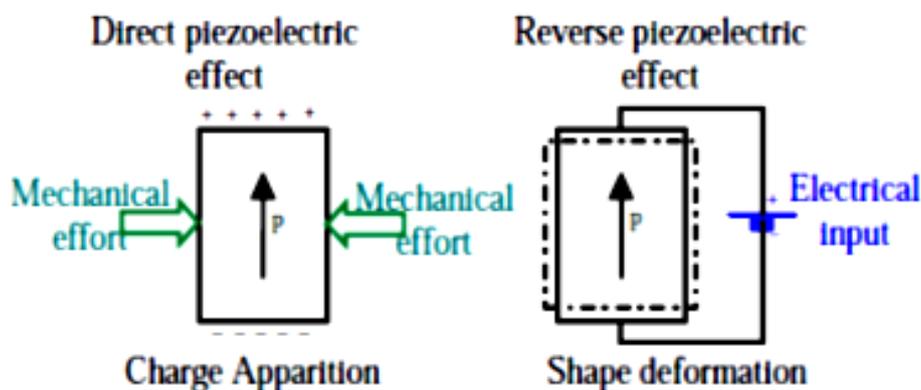

Fig. 1. *Working mechanism of simple piezo transducer (Anon [11]).*

VIBRATION MONITORING AND RECORDING INSTRUMENTS (SEISMOGRAPHS)

Many types of seismographs are available today. Each performs the basic function of measuring ground motion but supplies much additional information. Most seismographs are equipped with meters that register and hold the maximum value of the vibration components and the sound level. Other seismographs are equipped to produce a printout which gives a variety of information such as maximum value for each component, frequency of vibration for the maximum value, maximum displacement, maximum acceleration, vector sum, and sound level. Blast information such as date, blast number, time, location, job designation, and other pertinent information can also be added to the printout (Konya and Walter [12]).

SEISMIC ENERGY

The energy transferred into the strata in the form of seismic waves is calculated as the integral of the energy flow past a control surface at a given distance from the blast. The energy flux (power or rate of energy dissipated per unit area) is the scalar product of the stress at the surface and the particle velocity (Achenbach [13]). Calculations of seismic energy and its comparison with explosive energy have been reported by many researchers like Howell and Budenstein [14], Fogelson et al. [15], Berg and Cook [16], Nicholls [17], Atchinson [18], and more recently by Hinzen [19]. Berta [20] attempted to use some of the energy concepts in his principles of blast design, though this is seldom used in practice. The seismic energy dissipated by a ground vibration event at a given distance from blast site could be a critical component in assessing performance of blasts.

ASSESSMENT OF SEISMIC ENERGY

Ground Vibrations Monitoring

Intensity of ground vibrations generated due to blasting operations were monitored using 3 units of Minimate Plus, Instantel, Canada. These ground vibration monitors are of 8-Channeled instruments with six channels recording three mutually orthogonal ground vibration components, namely Transverse, Vertical and Longitudinal at two locations. The fourth and eighth channel records the noise level using microphone. Minimates with geophones and microphones connected are placed at different distances covering both short and long range distances, from the blast site. The vibration events were later transferred to a computer using advanced blastware software. Using the full wave forms, the seismic energy was estimated for all the signals in three directions, based on the principle that the area within the curve is 'Seismic Energy Dissipated' using DADiSP Signal Processing software. Care was taken to filter the noise.

DADiSP is a signal processing tool/software, using which shock energy dissipated in the form of waves is calculated. Longitudinal, transverse and vertical components of blast vibration events were imported from blastware software to digital signal processing software DADiSP in ASCII format. Fast Fourier transformation (FFT) was performed subsequently to find the frequency component of the time domain of blast wave signal as blast wave recorded by Minimate Plus and processed by Blastware falls in the category of random progressive signal. The estimation of absolute area describes the intrinsic energy of the blast wave signal distributed in various frequency bands. The energy of the signal x(t) is given by $\int_{-\infty}^{\infty} |x(t)|^2 \, dt$ (Sastry [21]).

FIELD INVESTIGATIONS AND RESULTS

Blasts were carried out in various mines for the extraction and assessment of seismic energy. Ground Vibration monitors were placed near blast field at various distances to find the impact of blast on nearby structures. Geophones were glued to the ground with the help of Plaster of Paris for proper contact. The piezo generator circuits were placed beside the conventional seismographs for maintaining accuracy in the obtained data. In total, 55 blasts were analyzed for the assessment of seismic energy based on electrical energy generation technique, out of which 10 blasts were carried out in Choutapalli limestone mine, 11 blasts were carried out in Yepalamadhavaram limestone mine and 34 blasts were carried out in coal mines of The Singareni Collieries Company Ltd. The following are some photographs depicting obtained electricity from undesirable seismic waves, extracted through piezo-gen circuit in various mine locations (Figure 2).

The various seismic data collected at various distances in different blasts were compared with the obtained electrical energy data as shown in Tables 1 and 2.
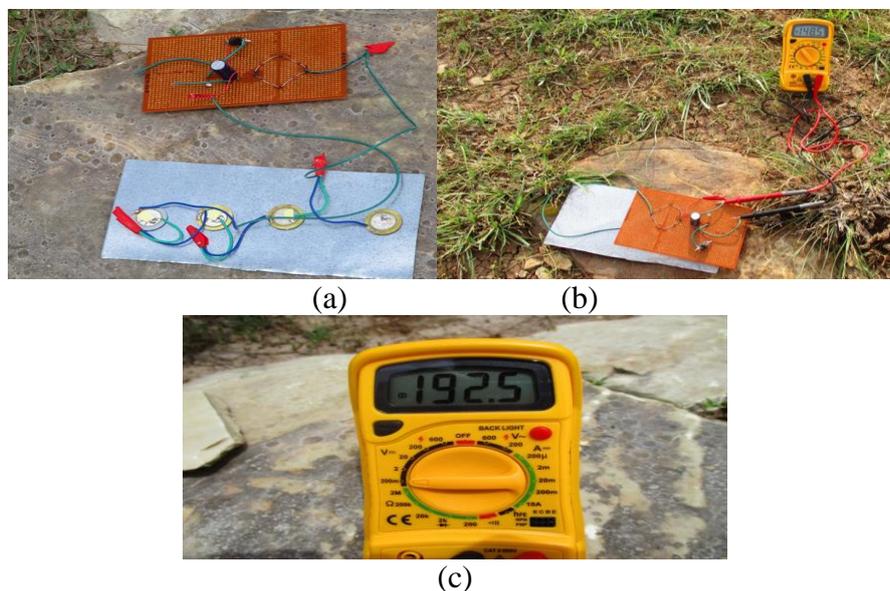

(a)   (b)

(c)

***Fig. 2.** (a) Piezo-Gen circuit. (b) Extraction of electricity using Piezo-Gen circuit from undesirable blast vibrations at limestone mine. (c) Observation of obtained voltage from the blast vibrations undesirable by multimeter for the assessment at limestone mine of seismic energy.*

***Table 1.** Summary of seismic energy extracted as electricity from blasts conducted in limestone mines.*

Sl. no.	Distance (m)	MCD (kg)	PPV (mm/s)	Seismic energy from three mutually orthogonal ground vibrations (MJ)	Electrical energy extracted from blast vibrations (MJ)
1	30	38.33	64.4	42256215	4509139.6
2	40	38.33	39.2	18524598	1963630.3
3	45	38.33	37.5	17108152	1709115.6
4	50	38.33	26.3	6729443	299095.23
5	55	38.33	22.5	14013633	1526210.7
6	60	38.33	11.8	6377533	248069.74
7	40	37.5	55.6	26656654	2424915.1
8	50	37.5	35.6	11103330	1041516.2

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9	55	37.5	29.3	5419536	234614.75
10	60	37.5	27.3	3903284	103863.11
11	65	37.5	26.4	18419851	1634399
12	65	37.5	22.7	7523677	460683.92
13	50	70.14	61	25837627	2571913.8
14	65	70.14	41.9	13666773	1407946
15	65	70.14	39.4	9824630	833789.96
16	70	70.14	32.5	2895806	64473.335
17	40	36.57	40	6548821	283286.87
18	50	36.57	30.1	4453486	123605.68
19	55	36.57	28.2	3232849	88722.367
20	70	36.57	16.1	712081	16118.334
21	75	36.57	10.4	964048	18693.452
22	80	36.57	3.43	306033	1931.3388
23	40	39.06	32.2	6893020	326396.26
24	50	39.06	28.2	6264554	243229.47
25	80	39.06	2.41	156568	95.374756
26	134	39.06	11.7	359719	3433.4912
27	40	39.28	171	59727766	7186831.2
28	50	39.28	181	99699604	11691266
29	55	39.28	68.8	27009086	3014047.3
30	75	39.28	10.3	2040307	40081.241
31	80	39.28	38.6	28970681	3120027.8
32	85	39.28	7.75	1901915	36266.251
33	50	51.4	118	21503717	2142627.3
34	60	51.4	126	111259278	13291238
35	65	51.4	91.4	58338415	6943699.5
36	90	51.4	38.1	5758561	262356.88
37	95	51.4	30.9	24691269	3269370.3
38	100	51.4	12.3	3366361	88722.367
39	30	24.58	44.7	23418621	2961119.1
40	38	24.58	42	38133182	4654974.8
41	50	24.58	23.7	9264400	633502.97
42	90	24.58	19.8	3331585	88722.367
43	95	24.58	18.4	4060162	110253.22
44	100	24.58	15	6492304	348280
45	40	14.35	34.8	3185760	80210.17
46	50	14.35	14.4	627148	13733.965
47	75	14.35	8.76	473566	8607.5717
48	80	14.35	8.13	240986	1168.3408
49	85	14.35	6.73	446799	6103.9844
50	40	30.36	34.4	12451737	1122775.5
51	50	30.36	23.1	8552912	550884.59
52	60	30.36	14.6	5350973	168241.07
53	70	30.36	11	1241977	24415.938
54	40	28.33	37.6	14565085	1699792.7
55	45	28.33	35.4	12675683	1164549.6
56	55	28.33	23.1	8573518	572844.63
57	70	28.33	15.5	4502870	137721.15

Typical sample event report and FFT reports generated from the blastware software (Figure 3). Seismic energy has obtained from the events recorded using signal processing tool, DADiSP. Sample of signal processing window is shown in Figure 4.

Table 2. *Summary of seismic energy extracted as electricity from blasts conducted in coal mine.*

Sl. no.	Distance (m)	MCD (kg)	PPV (mm/s)	Seismic Energy from three mutually orthogonal ground vibrations (MJ)	Electrical Energy Extracted from blast vibrations (MJ)
1	100	66	53.5	2738832.38	547766.476
2	110	66	33.8	1511665.32	151166.532
3	120	66	29.3	1470468.86	147046.886
4	150	66	18.92	6916156.65	4841309.66
5	160	66	17.4	5245447.1	3147268.26
6	170	66	17.3	8461652.43	7615487.19
7	184	50	5.33	1562458.55	1249966.84
8	178	88	22.61	9277651.8	7422121.44
9	188	88	20.2	4747405.68	2373702.84
10	200	88	17.9	366544.54	36654.454
11	292	88	4.06	376992.65	188496.325
12	150	85	19.81	10544797.7	10544797.7
13	209	85	10.7	2280225.67	456045.134
14	234	85	8.89	1055142.78	105514.278
15	295	85	3.3	134876.62	53950.648
16	696	450	3.56	513484.49	205393.796
17	719	450	1.52	136859.22	82115.532
18	750	450	1.52	171645.3	102987.18
19	800	450	1.02	1.836	1.836
20	603	460	7.11	1980472.55	594141.765
21	636	460	2.29	160142.93	112100.051
22	678	460	1.9	166647.59	66659.036
23	721	460	1.27	45698.08	45698.08
24	220	100	9.4	8769781.29	9646759.42
25	380	100	1.4	172599.58	172599.58
26	1591	1953	1.02	79583.75	79583.75
27	1856	1953	0.89	71031.38	71031.38
28	2033	1953	0.89	49481.5	49481.5
29	2121	1953	0.63	1.134	1.134
30	304	90	3.43	638174	638174
31	332	90	2.67	164876	98925.6
32	379	90	1.14	61901.33	111422.394
33	280	100	4.32	615873.463	123174.693
34	290	100	2.92	73406.109	44043.6654
35	300	100	2.03	402677.92	402677.92
36	440	100	1.27	108396.33	108396.33
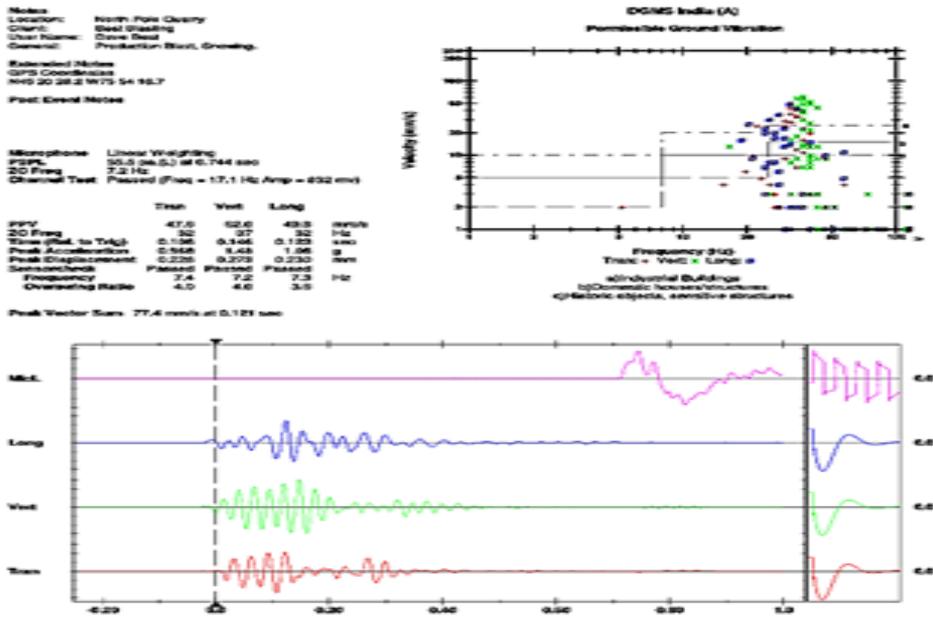
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(a)

(b)

Fig. 3. *Screenshots of vibration events recorded by minimate plus. (a) Typical event report,
(b) typical FFT report from blastware.*
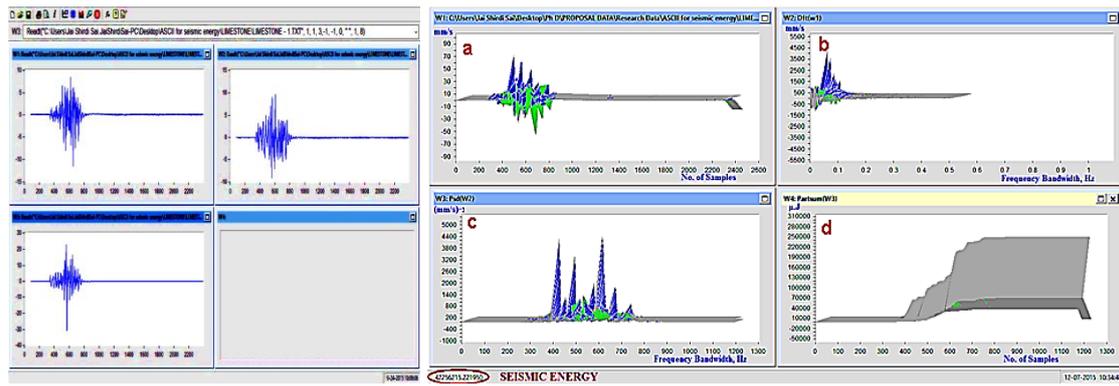
(a)   (b)

Fig. 4. *Finding of shock energy dissipated using DADiSP. (a) Signal processing window, (b) estimation of seismic energy.*

Also, comparison of seismic energy with the generated electrical energy was made to observe the amount of undesirable vibrations which were converted to electricity (Figure 5). From the analysis, it was observed that amount of seismic energy extracted in the form of electricity is 80–90% of the total seismic energy in limestone mines and that is about 75–80% in the case of coal mines.
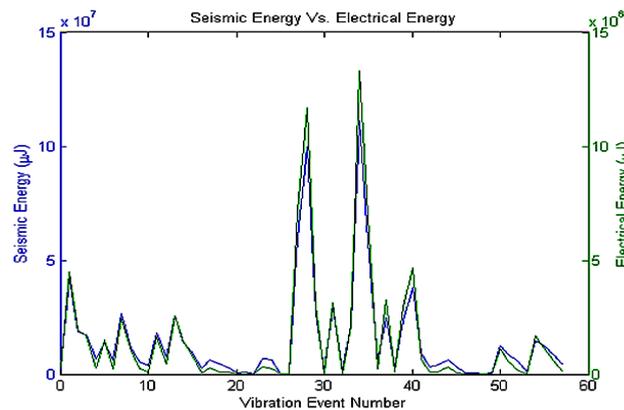
(a)
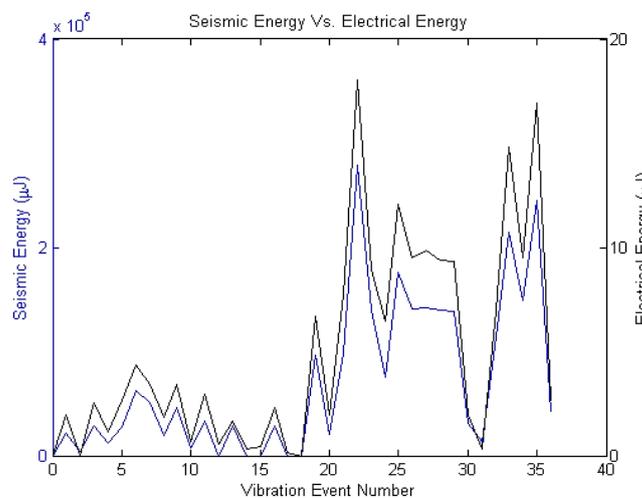
(b)

Fig. 5. *Amount of electrical energy extracted from blast induced vibrations with its corresponding seismic energy in various blasts. (a) In limestone mines, (b) in coal mine.*

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CONCLUSIONS

Based on the study, the following conclusions are drawn:

- Studies indicated that the amount of seismic energy is increased with the increase in maximum charge per delay. Hence, the optimal usage of MCD improves the performance of blasts by reducing seismic energy loss and improving explosive energy utilization.
- Seismic waves in the form of ground vibrations induced due to blasts can be efficiently tapped and converted with the help of Piezo-Gen circuit into useful electrical energy.
- The amount of seismic energy obtained in case of limestone mines is higher than in coal mines.
- The Piezo-Gen circuit may become a renewable source for generation of electricity from ground vibrations caused by blasting operations and further will be more useful in assessing the seismic energy in blast field.

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