SMART RUNWAYS-use of the residual wakes and semi infinite impulse transmission to produce electricity

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Abstract- The importance of aviation industry in modern era is long familiar. The industrial sector has been suffering energy crises from almost a decade or two and consequently paves way for the need of energy regeneration and utility. Runways are heart of an airport and currently runways are just used as pathways for airplane take off from the ground. The proposed idea emphasizes use of residual mechanical vibration energy from aircraft during takeoff, landing and taxing on ground. The question that arises, how do we achieve this?? The answer -Air Wakes and Impulse. Air Wakes are huge source of vibration energy and this paper discusses how these vibrations are harnessed using energy regenerative engineering technology. The total energy harvesting process is a three way phenomena, the first phase uses the huge air vibration impact on the elliptical dishes to set the body into SHM, subsequently leading to a spoke impact to a piezoelectric block resulting in potential (EMF) development This part of the research has already been accepted and under publication for ICEII 2013, Copenhagen, Denmark. This paper focuses on the Second module, complimentary to the first which uses the landing impact force (vibration) to set a hammer like engineered set up into SHM and strike medium to High quality piezoelectric plates to produce EMF. The designed module attains huge acceleration and transfers the impact onto a piezoelectric strip adjacent to it. The mechanical structures are then coupled to a base flip rectifier circuit, developing controlled voltages. Also, as an optional objective, all setups preferably 20 of them are planned to be electronically interfaced, reducing the need of manual maintenance and digital control of the modules. The main principles used in this module of the research are the use of smart materials and the principles of forced Vibration (undamped- Base excitation). Varieties of efficient piezoelectric harnessers are being developed using different vibration analysis and many have embarked upon the idea. But this paper is unparallel to those in many ways.

Index Terms- Air wakes, Bias Flip, Hammer, Piezoelectric.

I. Introduction

The basic concept is to transmit the impulse transmitted by the landing aircraft on a semi infinite plane [1], eventually striking a hammer shaped resonating adaptive structure, which acts as a vibration harnesser. This whole set up is placed deliberately at a calculated depth, over a free moving ball joint (which in turn is freely suspended by rods). The impact gets transmitted to the set up and the whole module is under forced vibration. This structure is then impacted upon thin piezoelectric strips [2], consequently producing electricity. The major concern in the mechanism is to ensure the longer period of the sustenance of the impact on the piezoelectric material, this is achieved by placing the hammer shaped impacting unit over a ball joint set up giving the oscillatory motion and the tension spring are attached as well to statically balanced the ball joint, thus allowing only the hammer to oscillate, enduring the period of impact and hence an amplified net electric potential is developed. First we will discuss the impulsive force, their generation and transmission over a semi infinite plane, followed by the piezoelectric materials and the Base- Flip rectifier Circuit deployed to produce the electric potential. Moving on we shall present the assembly of the components and how they are integrated with the electrical circuits and meshed with each other. Then we shall proceed with the discussion design calculations performed and stability analysis of the structure. The test results and the complete concept of operations have been explained.

II. Nomenclature

A. Piezoelectric materials

There are certain non conducting materials, such as quartz crystals and ceramics, when subjected to mechanical stress (such as pressure or vibration) develop electric charges, or the generation of vibrations in such materials when they are subjected to an electric field. Piezoelectric materials when exposed to fairly constant electric field tend to vibrate at a precise frequency with very little variation, making them useful as time-keeping devices wristwatches and also find its application in computers.[3]

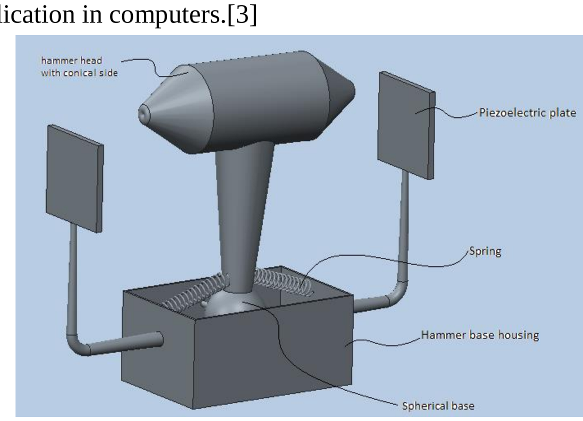

Figure 1: Solid model of Hammer Assembly

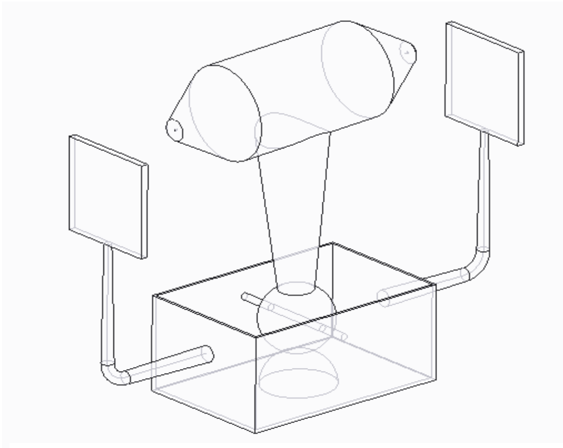

Figure 2: Wire diagram of Hammer Assembly

B. Assembly

The setup to generate electricity is installed on the side of runway strip in the landing area, extending up to the threshold landing space which is stated in accordance to CIVIL AVIATION REGULATIONS as 190m (max) from the runway end. The setup will be placed in the fly-over area but just beside the runway line which permits the presence of ditches and drains below ground level.

The major components of the module are broadly divided as follows:

A. Hammer Shaped Impactor

This is the main impact transmitting device, transferring the impulse received from the runways to the piezoelectric strips, placed on both the sides of the module as shown in the figure. The hammer's mass distribution is kept such that the greater mass inertia can be developed at the pointer tip, as labeled. This ensures as soon as the impact is imparted, the ball joint rolls and hence the hammer shakes. This swinging actuator then hits the two piezoelectric strips placed closely to the base side faces. This provides the necessary mechanical impact on the strips.

B. Spherical Base Support

This is the impulse transmitting member to the hammer. The hammer base is rested on this spherical base. The support is engineered to be kept at the centre of the rectangular base (see fig.1&fig.2) by means of the cylindrical rods attached to it on all the faces, thus all motions of this joint are arrested and only the twisting is allowed once the whole module receives vibration. This twisting force is transmitted to the hammer and the mechanical impact is developed.

C. Piezoelectric Strips

Piezoelectric plates are joined through pipes of varying cross section area emerging from the hammer ball joint housing. Any in coming disturbances will tend to displace its position from rest and the hammer will exhibit free oscillations hitting alternatively the piezoelectric plates on its left and right.

D. Delivery Circuit

The above assembly uses a circuitry to harness electricity from piezoelectric using a full bridge bias flip circuit.

Piezoelectric element can idealized as an equivalent circuit where mechanical domain is coupled with the electrical domain through a transformer that convert strain to current (Figure1). Here, L_M represents the mechanical mass, C_M represents mechanical stiffness and R_M takes into account the mechanical losses and C_P, R_P represents the capacitance and resistance of the piezoelectric material respectively. The input vibrations are sinusoidal in nature as $i_P = I_P \sin \omega_P t$.

Where $\omega_P = 2\pi f_P$, f_P is frequency of excitation.

E. Bias Flip Rectifier

A bias flip circuit is a modified voltage doubler circuit in which two rectifiers gets replaced by an inductor and a switch. In bridge rectifier losses are incurred in charging C_P , these can be easily covered up using a Bias Flip rectifier. A Bias Flip rectifier (Figure 2) uses a switch M_1 coupled with an inductor L_{BF} placed parallel with capacitor C_P [4]. The inductor L_{BF} passively flips the voltage across a capacitor C_P. At every half cycle when i_p changes its direction, the switch M_1 is turned ON briefly to allow the inductor to flip voltage across C_P. The switch is turned OFF when the current in the inductor reaches zero. Now the piezoelectric current only has to charge up C_P from the flipped voltage to $\pm(V_{RECT}+2V_D)$ before it can flow to the output. Therefore in doing this a significant amount of charge loss is reduced and majority of the charge can go into the output capacitor.

For power analysis of Bias flip circuit, we assume R_{BF} be the resistance along $L_{BF}-C_P$ path. When the switch is ON, the inductor helps in flipping in an efficient manner, the voltage (V_{BF}) across C_P. The resistance R_{BF} limits the magnitude of the flipping. Ideally the switch needs to be turned OFF exactly when the inductor current reaches zero to achieve maximal flipping of the voltage across C_P. Assuming the voltage across C_P starts at $V_{RECT}+2V_D$ [5] when the switch is turned ON , the final voltage across C_P after bias flipping can be derived to be

$$V_{BF}(\text{final}) = -(V_{RECT}+2V_D)e^{-\tau} \quad \ldots(1)$$

Where $\tau = \pi\beta/\omega$, $\beta = R_{BF}/2L_B$, $\omega = \sqrt{\omega_o^2 - \beta^2}$ and $\omega_o = 1/\sqrt{L_{BF} C_P}$.

Once the bias flipping takes place, the piezoelectric current i_P has to only change C_P from the voltage across it after the flipping to $\pm(V_{RECT}+2V_D)$.

The power delivered to the output by the bias flip rectifier can be given by

$$P_{RECT} = 2C_P V_{RECT} f_P [2V_P - (V_{RECT}+2V_D)(1-e^{-\tau})] \quad \ldots(2)$$

III. EQUATIONS, TRANSFORMATIONS AND RESULTS

A. Equations and Transformation

The following discusses the math behind the whole process of impact transfer, guided by the tension springs at the base of the

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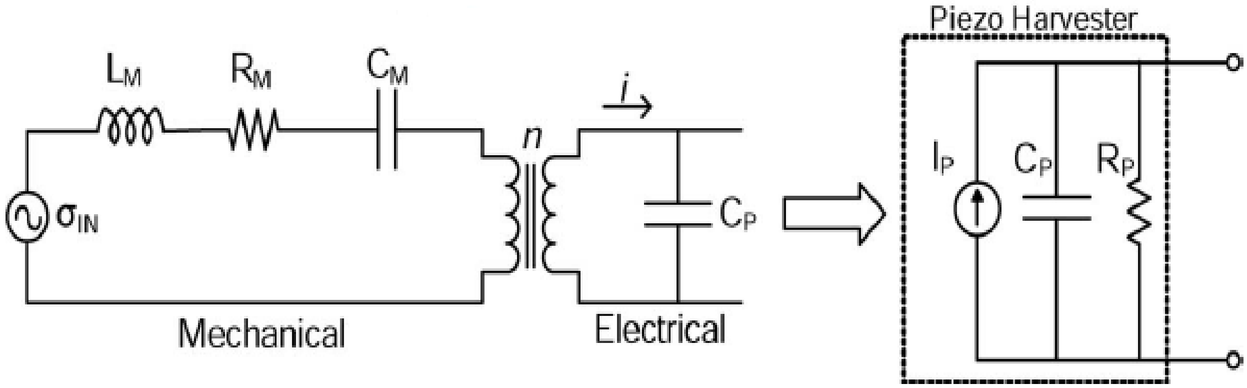

Figure3: Idealization of a piezoelectric circuit in form of a spring mass system

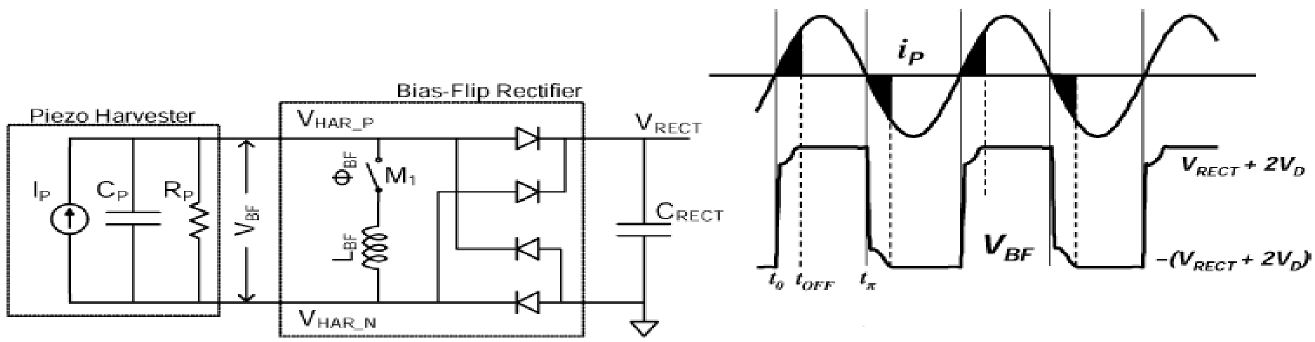

Figure4: A bias flip circuit and its characteristic curve

module. The calculations involve many assumptions to scale down the complexity.[6]

The spring forces at the base of the module are given as:

$F_1 = k_1.x_1$ … (3)

$F_1 = k_2.x_2$ … (4)

The two forces are resolved in the vertical direction as,

$F = f_1\sin\theta_1 + f_2\sin\theta_2$ … (5)

This balances weight of the hammer on its own (self weight).

Meanwhile, the other component of the spring forces represented as in equation (3) provide the moment at the base of the set up leading to the development of couple.

$f_1\cos\theta_1 + f_2\cos\theta_2$ ….(6)

The net couple equation can be described as in

$= f_1\cos\theta_1 \times r_1 + f_2\cos\theta_2 \times r_2$ Assuming $(r_1=r_2)$ …(7)

Assuming the two spring are identical and have the same properties, the moment equation can be written as

$F\cos 2\theta \times d$ …(8)

From the universal relations for the torque and shear forces as listed in

$\frac{T}{J} = \frac{\tau}{R}$ …(9)

$T = \pi d^4/32$ …(10)

$\tau = \frac{T}{J} \times R$ … (11)

assuming $\tau = 150 N/mm^2$

$R = \frac{\tau \times T}{J}$ … (12)

The equation decides the height of the hammer. This helps us decide one of the design constraints. The torque equation obtained by the angular acceleration values using the definite relations, the quantitative values of impact can be obtained.

$\tau = I \times \alpha$ … (13)

$a = R \times \alpha$ … (14)

Using the equations of motion, the equation gives the expected linear velocity value assuming the system to be conservative for simplicity.

$v^2 = u^2 + 2aR$ … (15)

here $u=0$

$v^2 = 2as$ … (16)

$\frac{1}{2}mv^2 = mgh$ …(17)

$v^2 = 2gh$ … (18)

$v = \sqrt{2gh}$ … (19

The assumption of the conservative behavior leads us to the equation where in the two velocity equations are compared. From the design methodology adopted for an assumed stress value the R value is known. This value is then used in the equation to get the height of the module.

$2aR = 2gh$ … (20)

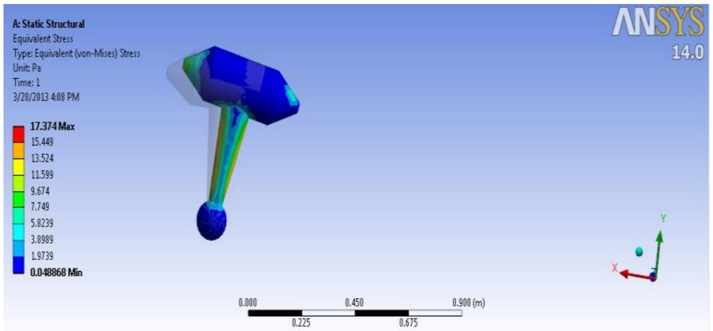

Figure5: Static structural analysis showing stress distribution over the hammer

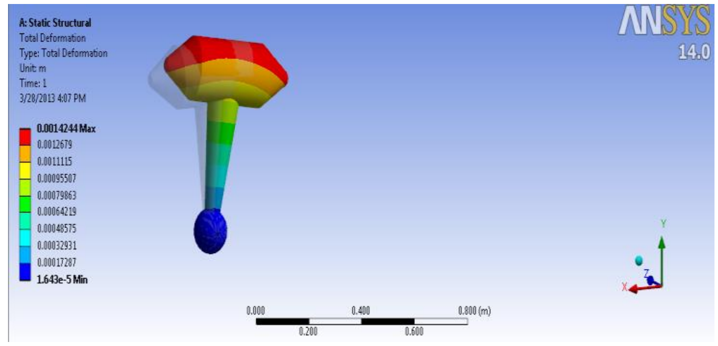

Figure6: Total deformation of hammer.

Table I

Sl No	Force F1 N	Force F2 N	F1cosA+F2cosB N	Pressure on the ball (N/m^2)	Pressure on the hammer (N/m^2)	Torque (T) N-m	Pressure on the tip (N/m^2)	Desired effect status
1	25	12.5	21.65	441.05	551.3125	1355	33079.5	positive
2	50	25	43.33	882.7115	1103.378	21000	66202.68	positive
3	75	37.5	64.95	1323.15	1653.9375	26000	99236.28	positive
4	100	50	86.6	1764.2	2205.25	13850	132315	positive
5	125	62.5	108.253	2205.312	2756.664	38000	165399.8	positive

Table II

Sl No.	Force F1 N	Force F2 N	F1cosA+F2cosB N	Couple C (Nm)	Height of the set up (m)	Torque (T) (Nm)	Moment (Nm)	Angular Acceleration	Acceleration (m/s^2)	Deflection (mm)
1	25	12.5	21.65	10.82	0.4	1355	2.0827	7615.5	3046.2	2.415
2	50	25	43.33	21.65	0.4	21000	4.0614	3807.75	1523.1	2.576
3	75	37.5	64.95	32.475	0.4	26000	6.08793	11423.25	4569.3	0.834
4	100	50	86.6	43.3	0.4	13850	81.875	15231.33	6092.52	10.16
5	125	62.5	108.253	54.126	0.4	38000	105.148	19039.16	7615.66	2.415

B. Analysis Results

The design is subjected to various values of impulse forces and validation of the endurance of the set up is the primary objective. The analysis of the assembly models are carried out in ANSYS 14 workbench. The two simulations carried out are stress and deformation analysis for various values of loads.

Stress Analysis

As desired stress (von-Mises stress) was found to be maximum at the tip of the cone on the hammer and was found to be 17.734Mpa. Also the stresses varied between 0.0489 to 17.734Mpa over the structure (See fig 5). The ball joint of the module was given a zero degree freedom constraint and the hammer was given an oscillatory motion freedom about the Z-Axis(X-Y Plane).

The design analysis also proved that the structure can withstand impact loads much higher than expected. Also, the actual force acting on hammer is the resultant of the twisting couple experienced by the ball joint transmitted to the hammer axially, after the whole set up is rendered unbalance on impact at the base rods. This sets the device in oscillation. Meanwhile, the largest pressure is created at the tip of the cone (side flange of the hammer) and thus imparting maximum impact on the piezoelectric strips, as expected. The following shows the real time result of the stress analysis.

Deformation analysis

The deformation of the hammer module was found to be maximum at the top portion of the hammer's lateral surface due to the impending twist and actuation, at the ball support rested centrally on the base. The maximum deformation of the module was found to be 0.0014244 m (See fig 6). The analysis was done keeping in mind that the set up is made up of an Aluminum alloy and similar properties of alloy was fed for obtaining solution and results of the simulation validated the need of extremely large pressure (much higher than actual loads) to cause even a minor deflection. The real time simulation results follow.[7]

TABLE I shows the numerical results obtained by calculating the sample impulse forces for a series of aircraft load impact (momentum transferred at the time of landing),Angular acceleration and moment values were obtained at the ball joint ,the erected hammer, The results were found satisfactory for all the cases. One of those cases has been cited.

TABLE II shows the numerical results on pressure variations at the ball joint, Pressure developed at the hammer tip, Torque imparted at the tip of the module and the resultant force developed at the nose cone on the sides of the hammer. All results were found to be positive.

IV. CONCLUSION

It is expected that using the above proposal it is possible to generate electricity and power up airport necessities. It will also be possible to power runway lighting. Besides that it will definitely help airports in maintaining their power budget. It's a completely pollution free, safe and green technique using smart materials (piezoelectric) and the impulse transmission, for continual extraction. Surely cost reduction as well as other benefits will be on a significant scale and if implied soon with other emerging energy harnessing solutions, it will yield give great results. The numerical and analytical tests carried out so far have shown positive outcomes and in the present era of energy crises the introduction of such energy harnessing modules will lead to a boom in the aviation sector and also make the idea of sustainability more realistic. The initial investment is the only constraint in the introduction of such technology, although in the longer run the idea will prove to be fruitful.

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