

1 Energy Harvesting System and Method of Manufacture

2

3 The present invention relates to an energy harvesting system and method of manufacture.
4 In particular, the described energy harvesting system is suitable for harvesting energy
5 from, an internal combustion engine of an automobile.

6

7 Background to the Invention

8

9 An internal combustion engine, as typically found in an automobile, converts chemical
10 energy into desired mechanical energy by combusting a fuel such that the expansion and
11 increase in pressure of the resulting gases drives a piston. An internal combustion engine
12 is not 100% efficient as energy is lost in the form of, primarily, thermal and vibrational
13 energy. In fact, a conventional automobile typically uses just 10% to 16% of the chemical
14 energy from the fuel to drive the automobile. In addition to the engine itself, there are
15 energy losses in, for example, the transmission, the brakes and even the rolling resistance
16 of the automobile. Nevertheless, the engine accounts for the largest energy loss within an
17 automobile of typically 63%.

18

1 The above described internal combustion engines and automobiles have numerous
2 disadvantages. For example, the operating inefficiencies result in a greater environmental
3 impact due to the increased levels of fuel consumption. As the fuel is typically derived
4 from a fossil fuel, which is a finite resource, the fossil fuels are depleted at an increased
5 rate. Furthermore, an inefficient engine and automobile will have a greater cost per mile.

6
7 In addition, the wasted energy may have negative consequences on the operation of the
8 internal combustion energy. For example, the excess vibrations may necessitate the
9 installation of expensive, vibrational damping mechanisms to limit the damage to the
10 engine and impact on the performance. Also, the excess thermal energy may require
11 additional expensive and heavy thermal installation to stop the engine from overheating.

12 13 Summary of the Invention

14
15 It is an object of an aspect of the present invention to provide an energy harvesting system
16 that obviates or at least mitigates one or more of the aforesaid disadvantages of the
17 energy harvesting systems known in the art.

18
19 According to a first aspect of the present invention there is provided a vibrational lens
20 comprising at least two focusing members, each of the at least two focusing members
21 having a proximal end for attachment to a vibrational source and a distal end, wherein the
22 at least two focusing members are arranged such that the separation between the
23 focusing members decreases from the proximal ends towards the distal ends.

24
25 Most preferably, the at least two focusing members each comprise a first portion located
26 between the proximal end and distal end. The first portions of the at least two focusing
27 members are angled relative to each other such that the at least two focusing members
28 converge at the distal ends.

29
30 Preferably, the at least two focusing members each comprise a second portion located at
31 the proximal end. Preferably, the second portions of the at least two focusing members
32 are substantially parallel.

33

1 Most preferably, the vibrational lens further comprises a backplate. The proximal ends of
2 the at least two focusing members may be fixed to the backplate. The second portions of
3 the at least two focusing members may be fixed to the backplate.
4
5 Preferably, the at least two focusing members each comprise a third portion located at the
6 distal end. The third portions of the at least two focusing members are substantially
7 parallel. The third portions of the at least two focusing members define a focal point of the
8 vibrational lens.
9
10 Preferably, the at least two focusing members comprise brass.
11
12 Optionally, the at least two focusing members comprise two or more layers and or
13 coatings. The two or more layers and or coatings may exhibit different vibrational and or
14 thermal characteristics. The at least two layers and or coatings may comprise different
15 dimensions, materials, densities and or grain structures.
16
17 Optionally, the at least two focusing members comprise a first layer and a second layer.
18 The first layer is fixed to the second layer. The first layer has a different coefficient of
19 thermal expansion to the second layer. The first layer may comprise brass. The second
20 layer may comprise steel.
21
22 Optionally, the vibrational lens further comprises one or more springs. The one or more
23 springs connect the at least two focusing members.
24
25 Optionally, the vibrational lens further comprises one or more weights attached to one or
26 more of the at least two focusing members.
27
28 Optionally, the vibrational lens further comprises a dynamic control system. The dynamic
29 control system changes the vibrational characteristics of the vibrational lens during
30 operation. The dynamic control system may adjust the stiffness of the spring. The
31 dynamic control system may adjust the location and or magnitude of the weights.
32
33 Optionally, the vibrational lens may comprise three focusing members.
34
35 Most preferably, the focusing members are focusing plates.

1

2 Alternatively, the focusing members are focusing rods.

3

4 According to a second aspect of the present invention there is provided an energy
5 harvesting system comprising a vibrational lens in accordance with the first aspect of the
6 present invention, a vibrational source and an energy conversion means.

7

8 Most preferably, a proximal end of the vibrational lens is fixed to the vibrational source.

9

10 Preferably, the vibrational source is an internal combustion engine.

11

12 Most preferably, the energy conversion means is located at a distal end of the vibrational
13 lens. Preferably, the energy conversion means is located between the third portions of the
14 at least two focusing members.

15

16 Preferably, the energy conversion means is one or more piezoelectric crystals.

17 Alternatively, the energy conversion means is one or more magnets and one or more coils.

18

19 Optionally, the energy harvesting system may further comprise one or more bimetallic
20 strips.

21

22 Optionally, the energy harvesting system may further comprise and one or more vibration
23 chambers.

24

25 Optionally, the vibration chamber comprises a first surface and a second surface.

26

27 Optionally, the vibration chamber is dimensioned relative to the distal end of the bimetallic
28 strip such that the bimetallic strip can strike the first and second surfaces of the vibration
29 chamber. The vibration chamber is dimension to be larger than the distal end of the
30 bimetallic strip.

31

32 Embodiments of the second aspect of the invention may comprise features to implement
33 the preferred or optional features of the first aspect of the invention or vice versa.

34

1 According to a third aspect of the present invention there is provided a method of
2 manufacturing a vibrational lens comprising:

- 3 - providing at least two focusing members, each having a proximal end for
4 attachment to a vibrational source and a distal end; and
- 5 - arranging the at least two focusing members such that the separation between the
6 at least two focusing members decreases from the proximal ends towards the
7 distal ends.

8

9 Most preferably, the method further comprises determining the characteristics of the
10 vibrational source.

11

12 Preferably, determining the characteristics of the vibrational source comprises quantifying
13 any one of the following parameters: revolutions per minute, noise level, engine gas
14 temperature, output power, torque and ambient temperature.

15

16 Most preferably, the method further comprises determining the optimum parameters of the
17 vibrational lens for use with the vibrational source.

18

19 Preferably, determining the optimum parameters of a vibrational lens comprises
20 determining an optimum length, width and or depth of the at least two focusing members;
21 and or the optimum separation of the proximal ends of the at least two focusing members;
22 and or the optimum separation of the distal ends of the at least two focusing members;
23 and or the optimum distance for the at least two focusing members to converge; and or the
24 optimum material or materials for the at least two focusing members; and or the optimum
25 coefficient of thermal expansion of the material or materials of the at least two focusing
26 members.

27

28 Optionally, determining the optimum length of the at least two focusing members
29 comprises attaching brass rods of different lengths to the vibrational source to determine
30 the resonant frequency across the operational range of the vibrational source.

31

32 Optionally, the method may further comprise determining the characteristics of a cyclic
33 temperature variation. The characteristics including the frequency and amplitude of the
34 cyclic temperature variation.

35

1 Optionally, providing at least two focusing members comprises providing the at least two
2 focusing members with two or more layers and or coatings.

3

4 Optionally, determining the optimum parameters may also include determining the
5 optimum vibrational and or thermal characteristics of the two or more layers and or
6 coatings of the at least two focusing members.

7

8 Optionally, determining the optimum parameters may also include: determining the
9 dimensions; and or the material composition; and or density; and or grain structure of the
10 two or more layers and or coatings of the at least two focusing members.

11

12 Optionally, determining the optimum parameters may also include: determining the depth
13 of a first layer and a second layer of the at least two focusing plates; the material of the
14 first layer; and the material of the second layer.

15

16 Optionally, providing a vibrational lens comprises providing the at least two focusing
17 members with a first layer and a second layer. The first layer having a different coefficient
18 of thermal expansion to the second layer. The first layer may comprise brass. The
19 second layer may comprise steel.

20

21 Embodiments of the third aspect of the invention may comprise features to implement the
22 preferred or optional features of the first and or second aspect of the invention or vice
23 versa.

24

25 According to a fourth aspect of the present invention there is provided a thermal energy
26 harvesting system comprising a bimetallic strip and an energy conversion means.

27

28 Most preferably, the energy conversion means may comprise a vibration chamber. A
29 distal end of the bimetallic strip is located within the vibration chamber.

30

31 Preferably, the vibration chamber comprises a first surface and a second surface.

32

33 Most preferably, the vibration chamber is dimensioned relative to the distal end of the
34 bimetallic strip such that the bimetallic strip can strike the first and second surfaces of the

1 vibration chamber. The vibration chamber is dimension to be larger than the distal end of
2 the bimetallic strip.

3

4 Most preferably, the first and or second surfaces may comprise one or more piezoelectric
5 crystals. The bimetallic strip may strike the one or more piezoelectric crystals located on
6 the first and or second surfaces of the vibration chamber.

7

8 Alternatively, the energy conversion means may comprise a magnet and a coil. The
9 magnet may be located at the distal end of the metallic strip. The coil may be centred
10 about the magnet. The coil may be orientated relative to the magnet such that any
11 deflection of the bimetallic strip moves the magnet within the centre of the coil.

12

13 Embodiments of the fourth aspect of the invention may comprise features to implement the
14 preferred or optional features of the first, second and or third aspect of the invention or
15 vice versa.

16

17 According to a fifth aspect of the present invention there is provided a method of
18 manufacturing a bimetallic strip comprising:

- 19 - determining the characteristics of a cyclic temperature variation;
- 20 - determining the optimum parameters of the bimetallic strip for use with the cyclic
21 temperature variation; and
- 22 - providing a bimetallic strip comprising a first layer and a second layer, according to
23 the optimum parameters.

24

25 Preferably, determining the characteristics of the cyclic temperature variation may
26 comprise determining the amplitude and or frequency of the cyclic temperature variation.

27

28 Preferably, determining the optimum parameters comprises determining the optimum
29 length, width and or depth of the bimetallic strip; and or the optimum depth of the first and
30 or second layer; and the optimum material of the first layer and or the second layer.

31

32 Optionally, providing a bimetallic strip may comprising providing three or more layers. The
33 three or more layers may each comprises different materials.

34

1 Embodiments of the fifth aspect of the invention may comprise features to implement the
2 preferred or optional features of the first, second, third and or fourth aspect of the invention
3 or vice versa.

4

5 According to a sixth aspect of the present invention there is provided a vibrational lens
6 comprising at least two focusing members, each of the at least two focusing members
7 having a proximal end and a distal end, wherein the separation between the distal ends of
8 the at least two focusing members is less than the separation between the proximal ends
9 of the at least two focusing members.

10

11 Embodiments of the sixth aspect of the invention may comprise features to implement the
12 preferred or optional features of the first, second, third, fourth and or fifth aspect of the
13 invention or vice versa.

14

15 Brief Description of Drawings

16

17 There will now be described, by way of example only, various embodiments of the
18 invention with reference to the drawings, of which:

19

20 Figure 1 presents a perspective view of a vibrational lens in accordance with an
21 embodiment of the present invention;

22

23 Figure 2 presents a schematic cross-sectional view of the vibrational lens of Figure 1;

24

25 Figure 3 presents a perspective view of a vibrational energy harvesting system comprising
26 the vibrational lens of Figure 1;

27

28 Figure 4 presents a schematic cross-sectional view of the vibrational energy harvesting
29 system of Figure 3;

30

31 Figure 5 presents a plot of (a) a voltage generated by a piezoelectric crystal of the
32 vibrational energy harvesting system of Figure 3 and (b) a voltage generated by a
33 reference piezoelectric crystal;

34

35 Figure 6 presents an alternative embodiment of the vibrational lens of Figure 1;

1
2 Figure 7 presents a further alternative embodiment of the vibrational lens of Figure 1;
3
4 Figure 8 presents a flow chart of the method of manufacturing the vibrational lens of Figure
5 1;
6
7 Figure 9 presents a perspective view of an apparatus used in the method of manufacture
8 of Figure 8;
9
10 Figure 10 presents a cross-sectional view of a bimetallic strip in accordance with the
11 present invention and the deflection of the bimetallic strip associate with a temperature
12 change from 22 °C to 150 °C as calculated from finite element modelling;
13
14 Figure 11 presents a plot of temperature and the deflection of bimetallic strip of Figure 10
15 as a function of time;
16
17 Figure 12 presents a schematic cross-sectional view of a thermal energy harvesting
18 system comprising the bimetallic strip of Figure 10;
19
20 Figure 13 presents a schematic cross-sectional view of an alternative thermal energy
21 harvesting system comprising the bimetallic strip of Figure 10;
22
23 Figure 14 presents a flow chart of the method of manufacturing the bimetallic strip of
24 Figure 10;
25
26 Figure 15 presents a schematic cross-sectional view of a combined vibrational and thermal
27 energy harvesting system in accordance with the present invention.
28
29 Figure 16 presents a schematic cross-sectional view of an alternative combined vibrational
30 and thermal energy harvesting system in accordance with the present invention.
31
32 In the description which follows, like parts are marked throughout the specification and
33 drawings with the same reference numerals. The drawings are not necessarily to scale
34 and the proportions of certain parts have been exaggerated to better illustrate details and
35 features of embodiments of the invention.

1

2 Detailed Description of the Preferred Embodiments

3

4 An explanation of the present invention will now be described with reference to Figures 1
5 to 16.

6

7 Vibrational Lens

8

9 Figures 1 and 2 depict a vibrational lens 1a. The vibrational lens 1a comprises a
10 backplate 2 and two focusing members. The focusing members take the form of a first
11 focusing plate 3 and a second focusing plate 4. The first and second focusing plates 3, 4
12 each have a proximal end 5 and a distal end 6. The first and second focusing plate 3, 4
13 each comprise a first portion 7, having a length γ , located between a second portion 8, at
14 the proximal end 5, and a third portion 9, at the distal end 6.

15

16 The second portion 8 of the first and second focusing plates 3, 4 is fixed to the backplate
17 2. As shown in Figure 1, the second portion 8 is angled to be substantially parallel and in
18 contact with the backplate 2 such that the second portion 8 is fixed to the backplate 2 by
19 welding. In addition to or as an alternative to welding, the fixture means may take the form
20 of an adhesive, a nut and a bolt, rivets, a combination thereof or any other suitable
21 alternative.

22

23 The second portions 8 of the first and second focusing plates 3, 4 are fixed to the
24 backplate 2 at substantially the same orientation and separated by distance α , as can be
25 seen in Figure 2.

26

27 As can also be seen in Figure 2, the first portions 7 of the first and second focusing plates
28 3, 4, are angled relative to the backplate 2 such that they converge towards each other. In
29 the presently described embodiment, the first portions 7 of the first and second focusing
30 plates 3, 4, are angled relative to the backplate 2 such that they converge towards a point
31 at a distance β along a normal to the backplate 2 located midway ($\alpha/2$) between the
32 second portions 8 of the first and second focusing plates 3, 4.

33

1 The third portions 9 at the distal end 6 of the first and second focusing plates 3, 4 are
2 angled to be substantially parallel, and preferably perpendicular to the backplate 2, and act
3 as the focal point of the vibrational lens 1a.

4

5 Vibrational Energy Harvesting System

6

7 Figures 3 and 4 depict the vibrational lens 1a as part of a vibrational energy harvesting
8 system 10. As well as the vibrational lens 1a, the vibrational energy harvesting system
9 further comprises a vibrational source 11 and an energy conversion means 12.

10

11 As depicted in Figures 3 and 4, the vibrational lens 1a is attached to the vibrational source
12 11 which takes the form of an internal combustion engine. The backplate 2 of the
13 vibrational lens 1a is fixed to the internal combustion engine 11, by for example nuts and
14 bolts, welding and or any other appropriate, equivalent means or combination thereof.

15

16 As can clearly be seen in Figure 4, located between the third portions 9 of the first and
17 second focusing plates 3, 4 is the energy conversion means 12 which takes the form of
18 one or more piezoelectric crystals. The piezoelectric crystals 12 are connected to
19 electrical components 13 and directed to, for example, an appropriate electrical load (not
20 shown) by cables 14. The one or more piezoelectric crystals 12 convert vibrational energy
21 originating from the internal combustion engine 11 into useful electrical energy. An
22 alternative energy conversion means could take the form of nano-coils and magnets.

23

24 Figure 5a shows the voltage as a function of time, generated by a piezoelectric crystal 12
25 located between the third portions 9 of the first and second focusing plates 3, 4 of the
26 vibrational lens 1a. Figure 5a depicts a root mean-square voltage of 0.743 V. Figure 5b
27 shows the voltage as a function of time, generated by a reference piezoelectric crystal (not
28 shown in the Figures) directly attached the internal combustion engine 11. Figure 5b
29 depicts a root mean-square voltage 0.003 V. The piezoelectric crystal 12 between the
30 third portions 9 generates a voltage approximately 248 times greater than the voltage of
31 the reference piezoelectric crystal.

32

33 The reason for this is that vibrational lens 1a transmits, converges and focuses vibrations
34 from the proximal end 5 to the distal end 6 of the focusing plates 3, 4. As such, the
35 focusing plates 3, 4 could be considered equivalent to a cantilever as the proximal end 5 of

1 each focusing plate 3, 4 is fixed to the backplate 2, and the distal end 6 is free to move,
2 actuating the piezoelectric crystals 12.

3

4 The focusing plates 3, 4 are substantially triangular, as can clearly be seen in Figure 1.
5 The proximal end 5 of the focusing plates 3, 4 are equivalent to the base of a triangle and
6 the distal end 6 equivalent to the (truncated) tip of a triangle. The triangular shape of the
7 focusing plates 3, 4 minimises the space required to house the vibrational lens 1a at the
8 perpendicular distance β from backplate 2 whilst maintaining functionality.

9

10 The vibrational lens 1a depicted in Figures 1 to 4 is made from brass due to the relatively
11 high density of brass which facilitates efficient transmission of vibrational energy through
12 the vibrational lens 1a. The vibrational lens 1a may alternatively be made from other
13 metals, alloys or even non-metallic materials, such as ceramics, suitable for transmitting
14 vibrational energy.

15

16 As an additional or alternative feature, the vibrational lens 1b of Figure 6, further
17 comprises a spring 15 between the first and second focusing plates 3, 4. It will be
18 appreciated that the vibrational lens 1b could comprise multiple springs 15. Similarly, as a
19 further additional or alternative feature the vibrational lens 1c of Figure 7, further
20 comprises a weight 16 attached to the first focusing plates 3. Again, it will be appreciated
21 that the vibrational lens 1c may comprise multiple weights 16 of equal or non-equal
22 weights located on both or just one of the first and second focusing plates 3, 4. As a
23 further alternative the vibrational lens 1 may comprise both a spring 15 and a weight 16.
24 Both the spring 15 and the weight 16 modify the vibrational characteristics of the
25 vibrational lens 1b, 1c by damping and or changing the resonant frequency of the
26 vibrational lens 1b, 1c, which provides a mechanism to optimise the characteristics of the
27 vibrational lens 1b, 1c. Figures 6 and 7 show the vibrational lens 1b, 1c may additionally
28 comprise a dynamic control system 17 to dynamically adjust the stiffness of the spring 15
29 and or location of the weight 16 on the first and or second focusing plates 3, 4 and or the
30 magnitude of the weight 16 on the first and or second focusing plates 3, 4. For example,
31 the weight 16 may take the form of a container into which water may be pumped in and or
32 out of by means of the dynamic control system 17. The dynamic control system 17
33 facilitates modifying the vibrational characteristics of the vibrational lens 1b, 1c during
34 operation.

35

1 As a further alternative, the vibrational lens 1a, 1b, 1c may comprise more or less than two
2 focusing plates 3, 4. For example, a vibrational lens 1a, 1b, 1c with just a first focusing
3 plate 3 could actuate piezoelectric crystals 12 located at the distal end 6 of the first
4 focusing plate 3 against the internal combustion engine 11, more specifically, a protruding
5 portion of the internal combustion engine housing. Conversely, a vibrational lens, 1a, 1b,
6 1c with three focusing plates 3, 4 may comprise two sets of piezoelectric crystals 12, one
7 set of piezoelectric crystals 12 between the distal end 6 of a first and a second focusing
8 plates, and the other set of piezoelectric crystals between the second and third focusing
9 plates.

10

11 As yet another alternative, instead of the vibrational lens 1a, 1b, 1c comprising a backplate
12 2, the focusing plates 3, 4 may be fixed directly to the vibrational source 11.

13

14 As a further alternative, instead of the vibrational lens 1a, 1b, 1c comprising focusing
15 plates 3, 4, the focusing members could take the form of focusing rods. Advantageously,
16 the focusing rods, such as those depicted in Figure 9, take up less space than the focusing
17 plates 3, 4.

18

19 As another additional or alternative feature, the focusing members may comprise multiple
20 layers and or coatings. The different layers and or coatings may exhibit different
21 vibrational and or thermal characteristics due to comprising, for example, different
22 dimensions, materials, densities and or grain structures.

23

24 For example, Figure 15 depicts focusing plates 3, 4 comprising a first, outer layer 20d and
25 a second, inner 21d layer. The second, inner layer 21d may be less dense than the first,
26 outer layer 20d. It is found this arrangement improves the transmission of vibrations
27 through the vibrational lens 1. As another example, the grain structure of the first, outer
28 layer 20d may be more aligned in comparison to the grain structure of the second, inner
29 layer 21d. Again, this arrangement improves the transmission of vibrations through the
30 vibrational lens 1. As a further example, the first, outer layer 20d may have a different
31 coefficient of thermal expansion in comparison to the second, inner layer 21d, in other
32 words the first layer 20d is made from brass and the second layer 21d is made from steel.
33 This arrangement induces vibrations and mimics the thermal properties of a bimetallic
34 strip, as discussed in more detail below. The planar layers 20d, 21d of the focusing plates

1 3, 4 as depicted in Figure 15 are equivalent to concentric layers and or coatings of a
2 focusing rod.

3

4 In addition, it is further noted the relative physical properties of the first, outer layer 20d
5 and the second, inner layer 21d may be reversed such that, for example, the second, inner
6 layer 21d may be more dense than the first, outer layer 20d. As a further alternative, the
7 grain structure of the first, outer layer 20d may be less aligned in comparison to the grain
8 structure of the second, inner layer 21d. The physical properties of the different layers
9 such as the dimensions, materials, densities and or grain structures are optimised
10 according to the desired vibrational and or thermal characteristics which ultimately
11 depends on frequency characteristics of the vibrational source 11.

12

13 Method of Manufacturing a Vibrational Lens

14

15 A method of manufacturing of the vibrational lens 1a, 1b, 1c will now be described with
16 reference to Figures 8 and 9.

17

18 Figure 8 shows a flow chart of the method of manufacturing the vibrational lens 1a, 1b, 1c
19 The vibrational lens 1a, 1b, 1c is manufactured such that it is optimised for a specific
20 vibrational source such as an internal combustion engine 11. First, the characteristics of
21 the internal combustion engine 11, are determined (S1001). For example, Table I shows
22 the change in noise level, engine gas temperature, output power, torque and ambient
23 temperature for the internal combustion engine 11, as the engine speed increases from
24 1260 to 3200 rpm.

25

Table I: Characteristic parameters of an internal combustion engine

Revolutions Per Minute (rpm)	Noise Level (dB)	Exhaust Gas Temperature (°C)	Power (kW)	Torque (Nm)	Ambient Temperature (°C)
1260	85.6	127	1.99	15.3	13.1
1318	85.2	121	1.60	12.2	11.6
1620	86.3	122	1.83	11.2	12.7
1890	90.9	118	1.29	6.5	13.1
2218	93.1	133	1.49	6.5	12.9
2520	97.3	152	1.72	6.4	14.3
2818	98.4	158	1.97	6.7	14.4
3200	100.9	178	2.63	7.7	14.1
3444	101.2	208	3.60	9.9	14.8

More specifically, from the lowest to highest rpm, the noise level increases by nearly 20 dB corresponding to the internal combustion engine 11 being approximately 4 times louder at the highest rpm and also indicating the vibrational energy loss within the internal combustion engine 11 increases with rpm. Similarly, the exhaust gas temperature increase from 127 to 208 °C from the lowest to highest rpm, indicating an increase in thermal loss from the internal combustion engine.

The method of manufacture further comprises the step of determining the optimum parameters for a vibrational lens 1a, 1b, 1c for harvesting the vibrational energy from a vibrational source, such as an internal combustion engine 11, as previously characterised (S1002). This includes determining the shape and dimensions of the vibrational lens 1a, 1b, 1c, such as, distances α , β and γ . More specifically, the optimisation may include dimensioning the length γ of the focusing plates 3, 4, to match an average resonant frequency across the operational range of the internal combustion engine (1260 to 3444 rpm). Figure 9 shows brass rods 18 of varying length attached to the internal combustion engine 11. Operating the internal combustion engine 11 and monitoring which rod 18 experiences the greatest deflection and or resonance, across the range of engine speeds (rpm) is indicative of the optimum value of γ . As indicated above, the focusing members could take the form of the brass rods 18, instead of or in addition to the focusing plates 3, 4.

1 The method of manufacture also comprises providing a vibrational lens 1a, 1b, 1c
2 according to the optimum parameters (S1003). More specifically, the focusing plates 3, 4
3 of the vibrational lens 1a, 1b, 1c are provided by water jet cutting brass plates to the
4 required dimensions and introducing appropriate bends in focusing plates 3, 4. The
5 focusing plates 3, 4 are welded to the backplate 2.

6
7 The method of manufacture may comprise optional additional steps of further optimising
8 the parameters of the vibrational lens 1a, 1b, 1c according to factors such as the type of
9 energy conversion means located at the distal end 6 of the focusing plates 3, 4, the
10 number of focusing plates 3, 4 the vibrational lens 1a, 1b, 1c comprises, the space
11 available to house the vibrational lens 1a, 1b, 1c and more generally the operational
12 constraints and desired performance characteristics. For example, the first portions 7 of
13 the first and second focusing plates 3, 4 are not limited to converging midway between the
14 second portions 8 of the first and second focusing plates 3, 4. In other words, the first
15 portions 7 of the focusing plates 3, 4 may be asymmetrically angled relative to the
16 backplate 2 to fit within the available space for housing the vibrational lens 1a, 1b, 1c and
17 or for a desired performance of the vibrational lens 1a, 1b, 1c.

18 Bimetallic Strip

19
20
21 Figure 10 depicts a bimetallic strip 19 comprising a first layer 20 and a second layer 21.
22 The first 20 and second 21 layers are fixed together, along the length and width of the
23 bimetallic strip 19, by means of: welding, an adhesive, nuts and bolts, rivets, a combination
24 thereof or any other suitable alternative. The first layer 20 is made from brass and the
25 second layer 21 is made from steel.

26
27 The first 20 and second 21 layers expand, or contract, at different rates in response a
28 temperature change, as brass has a different coefficient of thermal expansion (CTE) in
29 comparison to steel. The CTE for brass is $1.9 \times 10^{-5} \text{ }^{\circ}\text{C}^{-1}$ at $22 \text{ }^{\circ}\text{C}$ and the CTE for steel is
30 CTE of $1.01 \times 10^{-5} \text{ }^{\circ}\text{C}^{-1}$ at $22 \text{ }^{\circ}\text{C}$. The difference in expansion or contraction between the
31 first 20 and second 21 layers is most pronounced along the axis of the largest linear
32 dimension of the bimetallic strip 19, in other words, the z-axis of Figure 10 corresponding
33 to the length of the bimetallic strip 19. However, as the two layers 20, 21 are fixed
34 together, instead of noting a difference in length between the two layers 20, 21, the
35 bimetallic strip 19 bends in the in response to a temperature change.

The bimetallic strip 19 has a proximal end 22 and distal end 23. The proximal end 22 is fixed and the distal end 23 is free to move, akin to a cantilever. As shown in Figure 10, when the bimetallic plate 19 is heated, it bends in the negative y-direction as the first layer 20 has a larger CTE, the length expansion is greater relative to the second layer 21, so the first layer 20 is on the outer side of the curve. Conversely, when the bimetallic plate 19 is cooled, it bends in the positive y-direction. In short, the bimetallic strip 19 converts variations in temperature into the mechanical displacement.

More specifically, Figure 10 shows the result of finite element modelling of the thermal expansion of the bimetallic strip 19 undergoing a temperature change from 22 °C to 150 °C. The bimetallic strip 19 has a length of 300 mm along the z-axis, a width of 10 mm along the x-axis and a total depth of 5 mm along the y-axis. The first and second layers 20, 21 each layer has a depth of 2.5 mm. Figure 10 shows the distal end 23 of the bimetallic strip 19 has a maximum deflection of 15 mm.

As an extension of the finite element modelling of Figure 10, Figure 11 shows the variation in the deflection of the distal end 23 of the bimetallic strip 19 as a function of time, when the temperature cycles between 145 °C and 155 °C. The deflection experiences a cyclic change between approximately 14.8 to 15.9 mm. Figure 11 demonstrates that a cyclic temperature variation can be converted into a cyclic mechanical deflection.

Thermal Energy Harvesting System

Figure 12 depicts a thermal energy harvesting system 24a comprising the bimetallic strip 19 as described above and an energy conversion means which takes the form of a vibration chamber 25. The distal end 23 of the bimetallic strip 19 is located within the vibration chamber 25. The vibration chamber 25 is dimensioned such that as the distal end 23 of the bimetallic strip 19 periodically cycles between a deflection of, for example 14.8 to 15.9 mm, the distal end 23 strikes a first surface 26 and a second surface 27 of the vibration chamber 25. The first 26 and second 27 surfaces comprise piezoelectric crystals 12 such that the mechanical movement of the bimetallic strip 19 is converted into electrical energy. As before, the piezoelectric crystals 12 are connected to electrical components 13 and directed to an appropriate electrical load (not shown) by cables 14. In summary, the

1 thermal energy harvesting system 24 converts thermal energy into mechanical energy,
2 which is in turn converted into electrical energy.

3
4 In an alternative embodiment of the thermal energy harvesting system 24b, the energy
5 harvesting means may take the form of a magnet 28 and a coil 29. For example, as
6 shown in Figure 13, the magnet 28 is located at the distal end 23 of the metallic strip 19,
7 protruding along the y-axis, in the direction of the deflection. The coil 29 is orientated
8 relative to the magnet 28 such that the deflection of the bimetallic strip 19 periodically
9 moves the magnet 28 within the centre of the coil 29, resulting in a change in magnetic flux
10 and inducing a current in the coil 29.

11 12 Method of Manufacturing a Bimetallic Strip

13
14 Figure 14 depicts a flow chart describing a method of manufacturing the bimetallic strip 19.

15
16 The bimetallic strip 19 is manufactured such that it is optimised for a specific cyclic
17 temperature variation, such as, the cyclic temperature change experienced by a cylinder
18 within an internal combustion engine 11. The cylinder experiences a periodic burn of fuel
19 to drive a piston contained within the cylinder. The method of manufacture comprises,
20 first, characterising a cyclic temperature variation (S2001). For example, the temperature
21 may cycle between 145 to 155 °C, as assumed above in the context of the finite element
22 modelling.

23
24 For the bimetallic strip 19 to be sensitive to and oscillate with this cyclic temperature
25 variation, the method further comprises determining the optimum parameters of the
26 bimetallic strip 19 (S2002). The x, y and z dimensions of the bimetallic strip 19 and the
27 materials of the first and second layers 20, 21 are key parameters. For example, for a
28 bimetallic strip to exhibit a similar deflection for a small temperature variation relative to a
29 large temperature variation, the bimetallic strip would have to be dimensioned to be longer,
30 and the materials chosen to have a greater mismatch between the CTE. Another factor to
31 consider when optimising the parameters is the thermal conductivity of the chosen
32 materials. More specifically, the maximum frequency of a cyclic temperature variation is
33 limited by the minimum time required for the bimetallic strip 19 to exhibit a deflection in
34 response to a temperature change.

35

1 In addition, the method comprises providing a bimetallic strip 19 (S2003) in accordance
2 with the optimum parameters (S2002).

3 4 Combined Vibrational and Thermal Energy Harvesting System

5
6 Figure 15 depicts an energy harvesting system, more specifically, a combined vibration
7 and thermal energy harvesting system 30 which comprises the same and or similar
8 features to the vibrational energy harvesting system 10 of Figure 3 and 4 as described
9 above. The combined vibration and thermal energy harvesting system 30 comprises a
10 vibrational lens 1d attached to a source of vibrational and thermal energy 11, such as an
11 internal combustion engine, and an energy conversion means 12 which may take the form
12 of piezoelectric crystals.

13
14 The vibrational lens 1d as depicted in Figure 15 differs to the vibrational lens 1a, 1b, 1c as
15 described above, in that the first 3d and second 4d focusing plates both additionally
16 comprise a first 20d and second 21d layer. Instead of the focusing plates 3, 4 just being
17 made from a single material, the first layer 20d of the focusing plates 3d, 4d is made from
18 brass and the second layer 21d is made from steel, mimicking the layered structure and,
19 consequently, the resulting thermal properties of the bimetallic strip 19.

20
21 The vibrational lens 1d of Figure 15 harvests both the vibrational and thermal energy from
22 the internal combustion engine 11. A cyclic temperature variation from, for example, a
23 piston within the internal combustion engine 11 is converted to a cyclic deflection in the
24 vibrational lens 1d by means of the bimetallic structure. The vibrational lens 1d transmits,
25 converges and focuses both the cyclic mechanical deflection induced by the cyclic
26 temperature variation and the vibrations originating directly from the internal combustion
27 engine 11. The vibrational lens 1d actuates a piezoelectric crystal 12 which converts both
28 the vibrational and thermal energy into useful electricity.

29 30 Method of Manufacturing a Vibrational Lens with a Bimetallic Structure

31
32 A method of manufacturing the vibrational lens 1d for the combined vibrational and thermal
33 energy harvesting system comprises a combination of the steps in Figures 8 and 14.

34

1 The method comprises first characterising both the vibrational and thermal characteristics
2 of the source of vibrational and thermal energy (S1001, S2001). This includes quantifying
3 the frequency and amplitude of the cyclic temperature variation as well as the resonant
4 frequency across the operational range of the energy source.

5
6 The method further comprises determining the optimum parameters for a vibrational lens
7 1d with an integral bimetallic structure for use with a source of vibrational and thermal
8 energy (S1002, S2002). This includes determining the dimensions of the focusing plates
9 3d, 4d, including parameters α , β and γ as well as the depths of the first and second layers
10 20d, 21d and the material composition. It is envisaged that determining the optimum
11 parameters may comprise a balance between competing factors and this could be an
12 iterative process.

13
14 The method of manufacture includes (S1003, S2003) providing a vibrational lens 1d
15 according to the optimum parameters.

16 Alternative Combined Vibrational and Thermal Energy Harvesting System

17
18
19 Figure 16 depicts an alternative combined vibration and thermal energy harvesting system
20 31 which comprises the same and or similar features to the vibrational energy harvesting
21 system 10 of Figures 3 and 4 in conjunction with the same or similar features to the
22 thermal energy harvesting system of Figures 12.

23
24 The combined vibration and thermal energy harvesting system 31 comprises a vibrational
25 lens 1a, 1b, 1c, 1d, a bimetallic strip 19 and a vibration chamber 25. Similar to Figure 12,
26 the bimetallic strip 19 is attached to a source of vibrational and thermal energy 11 which
27 exhibits a cyclic temperature variation. In response to the cyclic temperature variation the
28 bimetallic strip 19 exhibits a cyclic deflection such that the bimetallic strip 19 strikes the
29 first and second surfaces 26, 27 of the vibration chamber 25. In contrast to Figure 12, the
30 vibration chamber 25 does not itself comprise an energy conversion means as, in this
31 combined vibration and thermal energy harvesting system 31, the bimetallic strip 19
32 enhances the vibrations exhibited by the source 11. The vibrational lens 1a, 1b, 1c, 1d is
33 attached to the vibration chamber 25 such that the lens 1a, 1b, 1c, 1d transmits,
34 converges and focuses both the vibrations originating directly from the source 11 and

1 thermally induced vibrations. An energy conversion means 12 located at the distal end 6
2 of the vibrational lens 1a, 1b, 1c, 1d converts the vibrational energy into useful electricity.

3

4 As an example, an internal combustion engine may comprise one or more bimetallic strips
5 and one or more vibration chambers to convert a thermal variation exhibited by a cylinder
6 of an internal combustion engine into vibrational energy. The vibrational energy of the
7 engine and the induced vibrational energy is converted by means of a vibrational lens into
8 electricity.

9

10 As an alternative, it is envisaged the vibrational lens 1a, 1b, 1c, 1d may be attached
11 directly to the source of vibrational and thermal energy 11.

12

13 As a further alternative, it is envisaged the combined vibration and thermal energy
14 harvesting system 31 may not comprise a vibration chamber 25 as described above, as
15 the movement of the bimetallic strip 19 alone may be sufficient to increase the vibrations
16 exhibited by the source 11.

17

18 A method of manufacturing the vibrational lens 1a, 1b, 1c, 1d and the bimetallic strip 19 for
19 the combined vibration and thermal energy harvesting system 31 comprises the steps of
20 Figures 8 and 14 respectively and as discussed above. A further consideration in the
21 context of system 31, is that when determining the optimum parameters for both the
22 vibrational lens 1a, 1b, 1c, 1d and the bimetallic strip 19 (S1002, S2002), additional
23 consideration may be given such that the vibrations induced by the bimetallic strip 19 are
24 resonant, matched and or correlated with the vibrational lens 1a, 1b, 1c, 1d. This may
25 involve further iterative optimisation of the dimensions and parameters of the vibrational
26 lens 1a, 1b, 1c, 1d and or the bimetallic strip 19.

27

28 Improving the efficiency of an internal combustion engine and an automobile by capturing
29 and recycling the wasted vibrational and thermal energy has numerous advantages. The
30 environmental impact of burning the fuel, typically derived from fossil fuels, is reduced and
31 the rate at which fossil fuels, a finite resource, are depleted is also reduced. Furthermore,
32 the cost per mile of the automobile will also be reduced due to the improved efficiency.

33

34 Vibrations and thermal losses within an internal combustion engine are typically
35 associated with inefficiencies in performance, limits in operation (e.g. overheating),

1 increased mechanical failure of components, a shorter lifespan of an engine and even
2 poor comfort within an automobile. Vibrational and thermal energy within an internal
3 combustion engine is typically wasted and as such, the norm is to minimise these losses
4 by introducing, for example, a damping mechanism and or even thermal insulation. In
5 contrast to this current understanding, the present invention does not minimise the
6 vibrations and or thermal losses but instead harvests the vibrational and thermal energy.
7 This results in the internal combustion engine being more energy efficient whilst mitigating
8 and even obviating the need all together for mechanisms to minimise these losses. This
9 can result in cost savings by not having to install expensive damping mechanisms to an
10 internal combustion engine.

11

12 A vibrational lens is disclosed. The vibrational lens comprises at least two focusing plates
13 each having a proximal and distal end. The separation between the distal ends of the at
14 least two focusing plates is less than the separation between the proximal ends of the at
15 least two focusing plates. The vibrational lens transmits, converges and focuses
16 vibrational energy from a source to an energy conversion means such as piezoelectric
17 crystals. The vibrational lens may also comprise a bimetallic structure to convert thermal
18 fluctuations into mechanical displacement. The vibrational lens is suitable for use in a
19 vibrational and or thermal energy harvesting system. Advantageously, the vibrational lens
20 improves the energy efficiency of, for example, an internal combustion engine whilst
21 mitigating the need for vibrational damping mechanisms and or thermal insulation.

22

23 Throughout the specification, unless the context demands otherwise, the terms “comprise”
24 or “include”, or variations such as “comprises” or “comprising”, “includes” or “including” will
25 be understood to imply the inclusion of a stated integer or group of integers, but not the
26 exclusion of any other integer or group of integers. Furthermore, unless the context clearly
27 demands otherwise, the term “or” will be interpreted as being inclusive not exclusive.

28

29 The foregoing description of the invention has been presented for purposes of illustration
30 and description and is not intended to be exhaustive or to limit the invention to the precise
31 form disclosed. The described embodiments were chosen and described in order to best
32 explain the principles of the invention and its practical application to thereby enable others
33 skilled in the art to best utilise the invention in various embodiments and with various
34 modifications as are suited to the particular use contemplated. Therefore, further

1 modifications or improvements may be incorporated without departing from the scope of
2 the invention as defined by the appended claims.

3

4