

Supplementary Material

Effect of Material Change on Stirnol Engine: A Combination of NiTiNOL (Shape Memory Alloy) and Gamma Stirling Engine

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S1. Stirling and Stirnol engines with base plate as aluminum

The different parameters calculated experimentally and further compared between a Stirling engine and Stirnol engine having base plates as aluminum is described in following paragraphs.

S1.1. Analysis of Temperature difference vs RPM

Table S1. Temperature difference vs RPM comparison of both engines.

| S No. | Temp of up- per plate (°C) | Temp of lower plate (°C) | Temp diff (°C) | Performance of Stirling engine RPM | Performance of Stirnol engine RPM |
|-------|----------------------------------|--------------------------------|-------------------|------------------------------------------|-----------------------------------------|
| 1 | 25 | 45 | 20 | 220 | 228 |
| 2 | 25 | 50 | 25 | 235 | 245 |
| 3 | 25 | 55 | 30 | 248 | 259 |
| 4 | 25 | 60 | 35 | 262 | 274 |

The Performance comparison of both the engines is shown in graphical form in Figure S1.

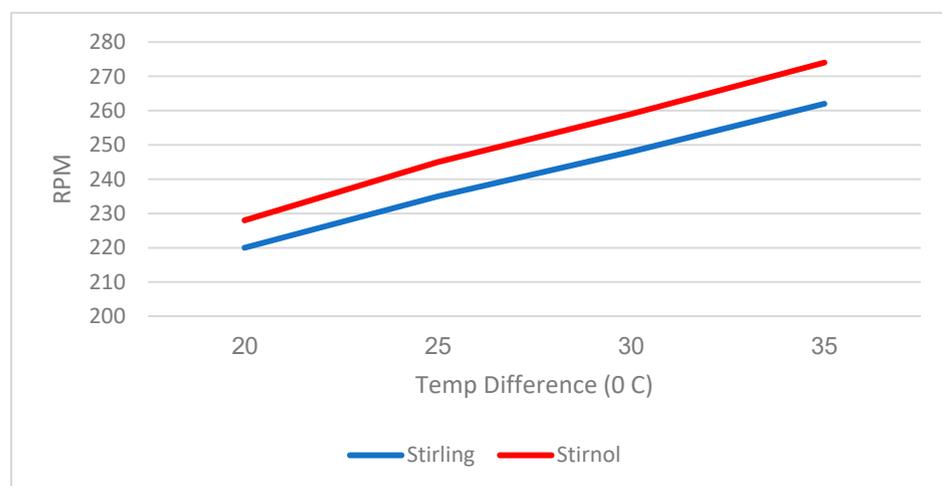


Figure S1. Performance comparison of Stirling and Stirnol engines.

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S1.2. Analysis of Brake power vs RPM

The brake power of an IC engine is the power available at the crankshaft. It is measured by the formula:

$$\text{Brake power} = \text{Torque} * \text{RPM} \tag{S1}$$

$$\text{Power (W)} = T \text{ (N.m)} * W \text{ (rad/sec)} \tag{S2}$$

Table S2. Analysis of Brake power vs RPM.

| S No. | Temp diff (°C) | Stirling engine | | Stirrol engine | |
|-------|----------------|-----------------|------------------|----------------|------------------|
| | | RPM | Brake power (mW) | RPM | Brake power (mW) |
| 1 | 20 | 220 | 0 | 228 | 0 |
| | | 190 | 1.3 | 200 | 1.5 |
| | | 115 | 2.2 | 130 | 2.5 |
| | | 70 | 2.0 | 77 | 2.4 |
| | | 35 | 1.5 | 41 | 1.9 |
| 2 | 25 | 235 | 0 | 245 | 0 |
| | | 218 | 1.35 | 224 | 1.6 |
| | | 150 | 2.7 | 158 | 3.0 |
| | | 100 | 2.9 | 110 | 3.3 |
| | | 40 | 2.3 | 47 | 2.5 |
| 3 | 30 | 248 | 0 | 259 | 0 |
| | | 232 | 1.43 | 241 | 1.5 |
| | | 160 | 3.15 | 168 | 3.3 |
| | | 100 | 3.3 | 109 | 3.2 |
| | | 33 | 2.4 | 39 | 2.7 |
| 4 | 35 | 262 | 0 | 274 | 0 |
| | | 240 | 1.65 | 252 | 1.9 |
| | | 170 | 3.5 | 178 | 3.8 |
| | | 105 | 3.65 | 112 | 3.7 |
| | | 40 | 3.0 | 47 | 3.4 |

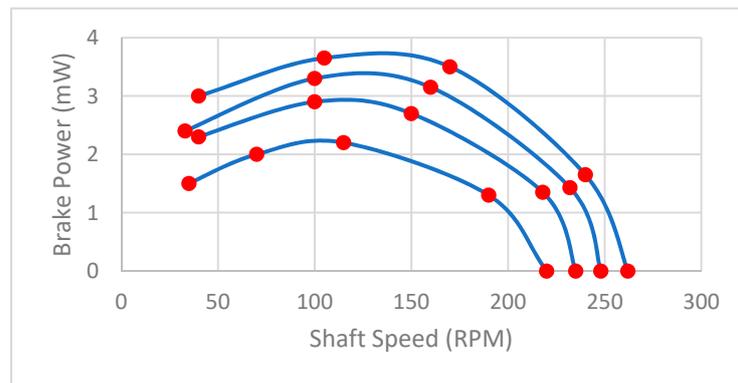


Figure S2. Brake power vs shaft speed of Stirling engine.

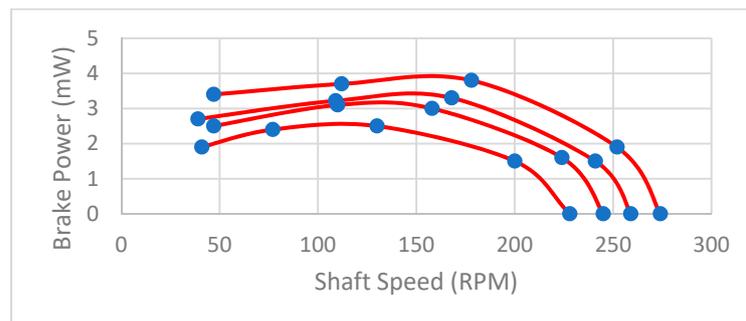


Figure S3. Brake power vs shaft speed of Stirrol engine.

S1.3. Analysis of Engine efficiency vs RPM

Thermal efficiency can be calculated by the following formula:

$$\text{Efficiency} = \text{Useful work done} / \text{Heat provided} \quad (\text{S3})$$

Table S3. Engine efficiency vs RPM of Stirling engine.

| S No | Temp diff (°C) | Aluminum - Max efficiency (%) |
|------|----------------|-------------------------------|
| 1 | 20 | 0.047 |
| 2 | 25 | 0.07 |
| 3 | 30 | 0.078 |
| 4 | 35 | 0.09 |

Table S4. Engine efficiency vs RPM of Stirinol engine.

| S No | Temp diff (°C) | Aluminum - Max efficiency (%) |
|------|----------------|-------------------------------|
| 1 | 20 | 0.063 |
| 2 | 25 | 0.075 |
| 3 | 30 | 0.09 |
| 4 | 35 | 0.1 |

S2. Stirling and Stirinol engines with base plate as copper

The second material used to conduct heat was selected as copper. The different parameters calculated experimentally and further compared between a Stirling engine and Stirinol engine having base plates as copper is described in following paragraphs.

S2.1. Analysis of Temperature difference vs RPM

Table S5. Temp difference vs RPM comparison of both engines.

| S No. | Temp of up- per plate (°C) | Temp of lower plate (°C) | Temp diff (°C) | Performance of Stirling engine RPM | Performance of Stirinol engine RPM |
|-------|----------------------------------|--------------------------------|-------------------|------------------------------------------|------------------------------------------|
| 1 | 25 | 45 | 20 | 355 | 365 |
| 2 | 25 | 50 | 25 | 372 | 390 |
| 3 | 25 | 55 | 30 | 400 | 415 |
| 4 | 25 | 60 | 35 | 422 | 440 |

The Performance comparison of both the engines is shown in graphical form in Figure S4.

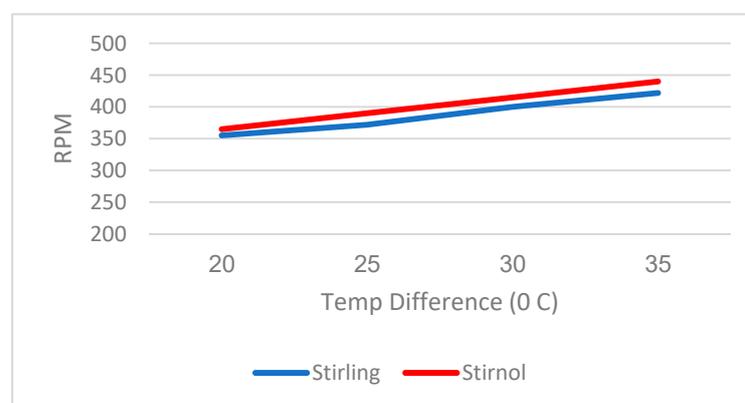


Figure S4. Performance comparison of Stirling and Stirinol engines.

S2.2. Analysis of Brake power vs RPM

The brake power of an IC engine is the power available at the crankshaft. It is measured by the formula:

$$\text{Brake power} = \text{Torque} * \text{RPM} \tag{S4}$$

$$\text{Power (W)} = T \text{ (N.m)} * W \text{ (rad/sec)} \tag{S5}$$

Table S6. Analysis of Brake power vs RPM.

| S No. | Temp diff (°C) | Stirling engine | | Stirrol engine | |
|-------|-------------------|-----------------|---------------------|----------------|---------------------|
| | | RPM | Brake power (mW) | RPM | Brake power (mW) |
| 1 | 20 | 352 | 0 | 365 | 0 |
| | | 290 | 2.05 | 300 | 2.2 |
| | | 220 | 3.45 | 230 | 3.8 |
| | | 150 | 3.1 | 165 | 3.65 |
| | | 70 | 2.2 | 85 | 2.8 |
| 2 | 25 | 376 | 0 | 390 | 0 |
| | | 310 | 2.1 | 320 | 2.4 |
| | | 230 | 4.2 | 245 | 4.6 |
| | | 165 | 4.45 | 175 | 5.05 |
| | | 80 | 3.55 | 95 | 3.85 |
| 3 | 30 | 400 | 0 | 415 | 0 |
| | | 330 | 2.18 | 350 | 2.25 |
| | | 255 | 4.8 | 275 | 5.05 |
| | | 185 | 5.15 | 200 | 5.2 |
| | | 100 | 3.8 | 110 | 4.25 |
| 4 | 35 | 422 | 0 | 440 | 0 |
| | | 355 | 2.5 | 370 | 2.8 |
| | | 280 | 5.42 | 300 | 5.8 |
| | | 210 | 5.62 | 225 | 5.72 |
| | | 130 | 4.5 | 155 | 5.2 |

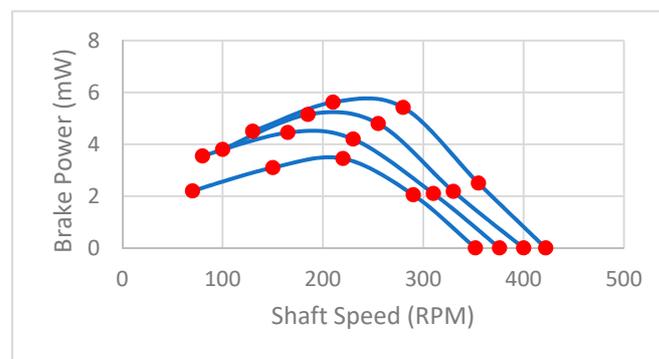


Figure S5. Brake power vs shaft speed of Stirling engine.

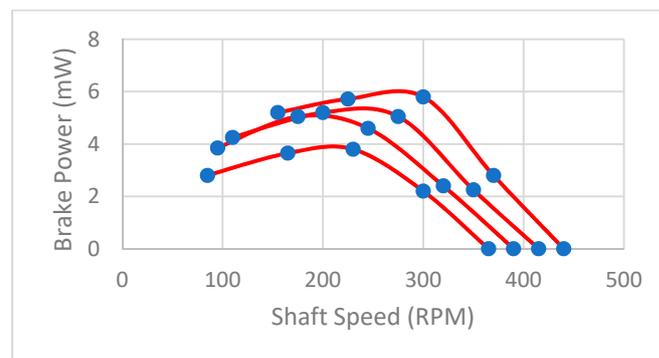


Figure S6. Brake power vs shaft speed of Stirrol engine.

S2.3. Analysis of Engine efficiency vs RPM

Thermal efficiency can be calculated by the following formula:

$$\text{Efficiency} = \text{Useful work done} / \text{Heat provided} \quad (\text{S6})$$

Table S7. Engine efficiency vs RPM of Stirling engine.

| S No | Temp diff (°C) | Copper - Max efficiency (%) |
|------|----------------|-----------------------------|
| 1 | 20 | 0.072 |
| 2 | 25 | 0.102 |
| 3 | 30 | 0.115 |
| 4 | 35 | 0.135 |

Table S8. Engine efficiency vs RPM of Stirnol engine.

| S No | Temp diff (°C) | Copper - Max efficiency (%) |
|------|----------------|-----------------------------|
| 1 | 20 | 0.1 |
| 2 | 25 | 0.11 |
| 3 | 30 | 0.13 |
| 4 | 35 | 0.145 |

S3. Stirling and Stirnol engines with base plate as brass

The fourth material used to conduct heat was selected as brass. The different parameters calculated experimentally and further compared between a Stirling engine and Stirnol engine having base plates as brass is described in following paragraphs.

S3.1. Analysis of Temperature difference vs RPM

Table S9. Temp difference vs RPM comparison of both engines.

| S No. | Temp of upper plate (°C) | Temp of lower plate (°C) | Temp diff (°C) | Performance of Stirling engine RPM | Performance of Stirnol engine RPM |
|-------|--------------------------|--------------------------|----------------|------------------------------------|-----------------------------------|
| 1 | 25 | 45 | 20 | 140 | 145 |
| 2 | 25 | 50 | 25 | 150 | 158 |
| 3 | 25 | 55 | 30 | 158 | 165 |
| 4 | 25 | 60 | 35 | 168 | 175 |

The Performance comparison of both the engines is shown in graphical form in Figure S7.

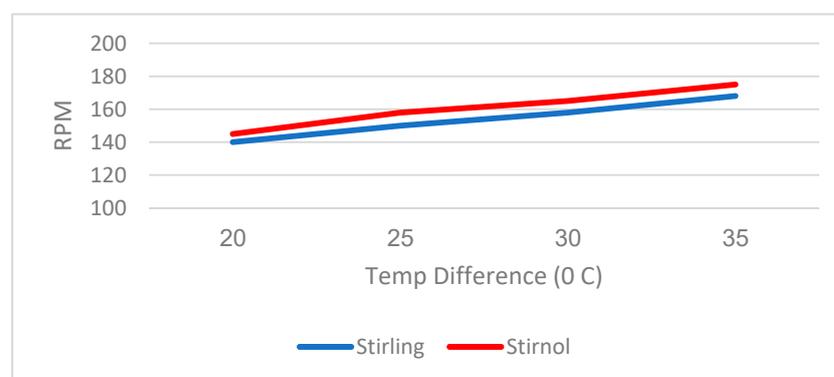


Figure S7. Performance comparison of Stirling and Stirnol engines.

S3.2. Analysis of Brake power vs RPM

The brake power of an IC engine is the power available at the crankshaft. It is measured by the formula:

$$\text{Brake power} = \text{Torque} * \text{RPM} \tag{S7}$$

$$\text{Power (W)} = T \text{ (N.m)} * W \text{ (rad/sec)} \tag{S8}$$

Table S10. Analysis of Brake power vs RPM.

| S No. | Temp diff (°C) | Stirling engine | | Stirrol engine | |
|-------|-------------------|-----------------|---------------------|----------------|---------------------|
| | | RPM | Brake power (mW) | RPM | Brake power (mW) |
| 1 | 20 | 140 | 0 | 145 | 0 |
| | | 120 | 0.8 | 125 | 0.95 |
| | | 95 | 1.4 | 100 | 1.6 |
| | | 70 | 1.2 | 75 | 1.5 |
| | | 35 | 0.95 | 37 | 1.2 |
| 2 | 25 | 150 | 0 | 158 | 0 |
| | | 130 | 0.85 | 135 | 1.0 |
| | | 105 | 1.7 | 110 | 1.9 |
| | | 80 | 1.81 | 85 | 2.1 |
| | | 40 | 1.5 | 42 | 1.58 |
| 3 | 30 | 158 | 0 | 165 | 0 |
| | | 135 | 0.9 | 143 | 0.95 |
| | | 110 | 1.99 | 121 | 2.1 |
| | | 85 | 2.1 | 98 | 2.0 |
| | | 43 | 1.5 | 48 | 1.7 |
| 4 | 35 | 168 | 0 | 175 | 0 |
| | | 145 | 1.02 | 153 | 1.2 |
| | | 120 | 2.2 | 128 | 2.4 |
| | | 95 | 2.3 | 105 | 2.3 |
| | | 48 | 1.89 | 55 | 2.15 |

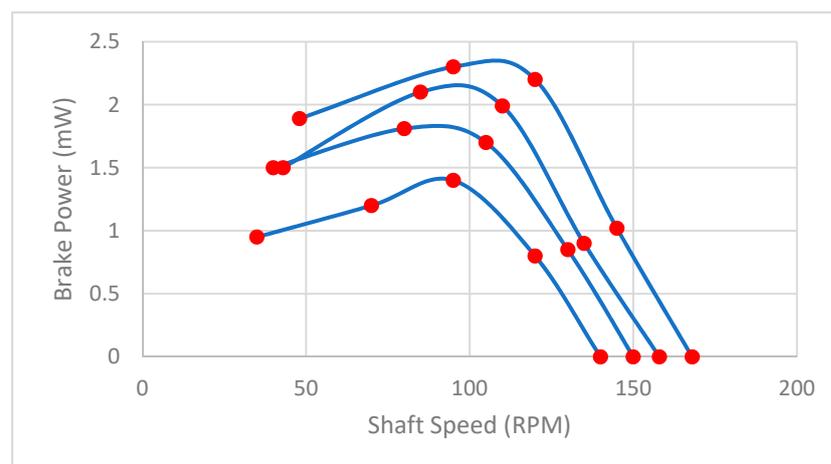


Figure S8. Brake power vs shaft speed of Stirling engine.

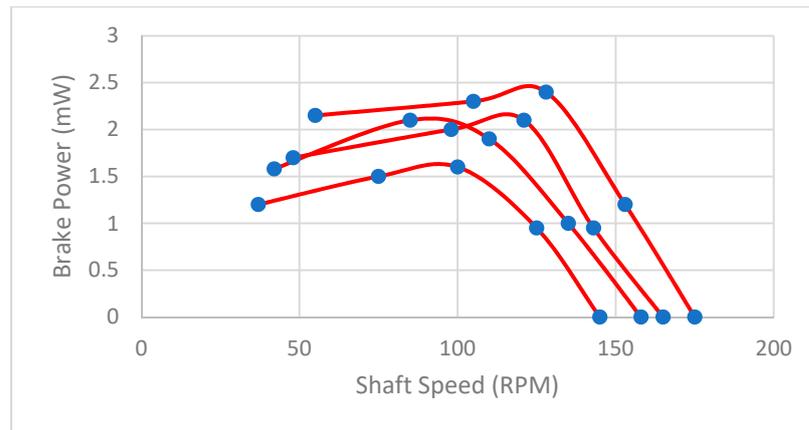


Figure S9. Brake power vs shaft speed of Stirling engine.

S3.3 Analysis of Engine efficiency vs RPM

Thermal efficiency can be calculated by the following formula:

$$\text{Efficiency} = \text{Useful work done} / \text{Heat provided} \tag{S9}$$

Table S11. Engine efficiency vs RPM of Stirling engine.

| S No | Temp diff (°C) | Brass - Max efficiency (%) |
|------|----------------|----------------------------|
| 1 | 20 | 0.028 |
| 2 | 25 | 0.041 |
| 3 | 30 | 0.045 |
| 4 | 35 | 0.05 |

Table S12. Engine efficiency vs RPM of Stirling engine.

| S No | Temp diff (°C) | Brass - Max efficiency (%) |
|------|----------------|----------------------------|
| 1 | 20 | 0.035 |
| 2 | 25 | 0.045 |
| 3 | 30 | 0.052 |
| 4 | 35 | 0.06 |

S4. Stirling and Stirling engines with base plate as bronze

The third material used to conduct heat was selected as bronze. The different parameters calculated experimentally and further compared between a Stirling engine and Stirling engine having base plates as bronze is described in following paragraphs.

S4.1. Analysis of Temperature difference vs RPM

Table S13. Temp difference vs RPM comparison of both engines.

| S No. | Temp of upper plate (°C) | Temp of lower plate (°C) | Temp diff (°C) | Performance of Stirling engine RPM | Performance of Stirling engine RPM |
|-------|--------------------------|--------------------------|----------------|------------------------------------|------------------------------------|
| 1 | 25 | 45 | 20 | 82 | 85 |
| 2 | 25 | 50 | 25 | 88 | 92 |
| 3 | 25 | 55 | 30 | 92 | 98 |
| 4 | 25 | 60 | 35 | 98 | 102 |

The Performance comparison of both the engines is shown in graphical form in Figure S10 which depicts that SMA has augmented the overall efficiency of the engine.

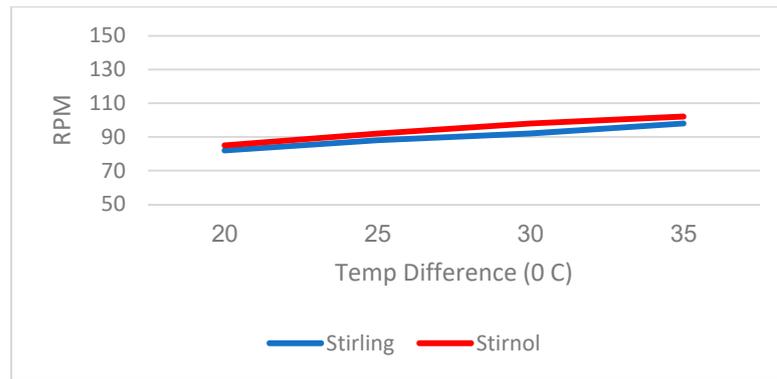


Figure S10. Performance comparison of Stirling and Stirinol engines.

S4.2. Analysis of Brake power vs RPM

The brake power of an IC engine is the power available at the crankshaft. It is measured by the formula:

$$\text{Brake power} = \text{Torque} * \text{RPM} \tag{S10}$$

$$\text{Power (W)} = T \text{ (N.m)} * W \text{ (rad/sec)} \tag{S11}$$

Table S14. Analysis of Brake power vs RPM.

| S No. | Temp diff (°C) | Stirling engine | | Stirinol engine | |
|-------|----------------|-----------------|------------------|-----------------|------------------|
| | | RPM | Brake power (mW) | RPM | Brake power (mW) |
| 1 | 20 | 82 | 0 | 85 | 0 |
| | | 60 | 0.5 | 64 | 0.55 |
| | | 45 | 0.75 | 45 | 0.75 |
| | | 30 | 0.6 | 34 | 0.65 |
| 2 | 25 | 88 | 0 | 92 | 0 |
| | | 65 | 0.55 | 72 | 0.61 |
| | | 48 | 0.82 | 56 | 0.94 |
| | | 35 | 0.65 | 43 | 0.72 |
| 3 | 30 | 92 | 0 | 99 | 0 |
| | | 72 | 0.6 | 77 | 0.68 |
| | | 55 | 0.92 | 62 | 0.52 |
| | | 42 | 0.7 | 51 | 0.85 |
| 4 | 35 | 98 | 0 | 102 | 0 |
| | | 75 | 0.65 | 79 | 0.70 |
| | | 60 | 0.98 | 65 | 0.55 |
| | | 48 | 0.74 | 53 | 0.88 |

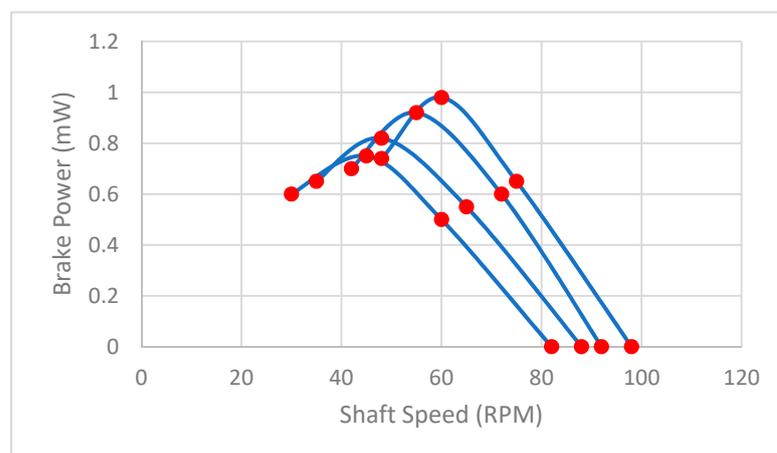


Figure S11. Brake power vs shaft speed of Stirling engine.

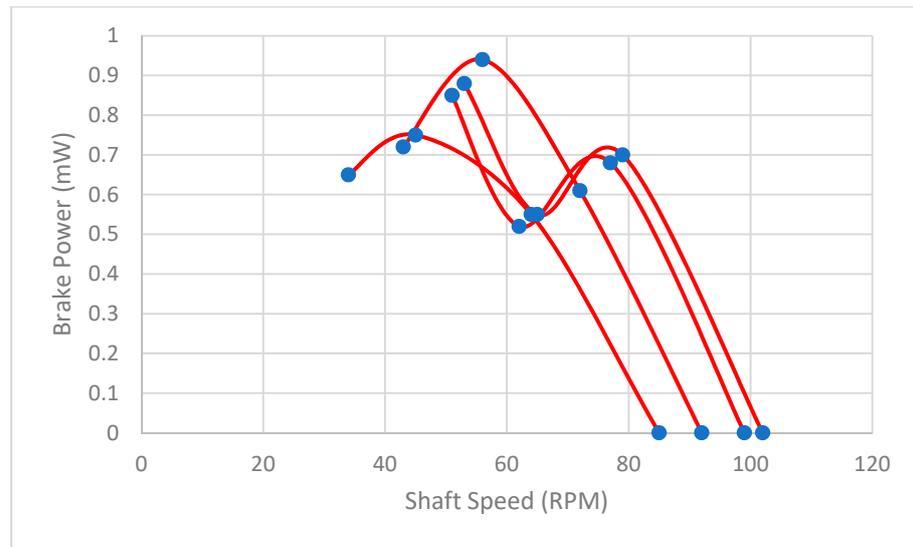


Figure S12. Brake power vs shaft speed of Stirling engine.

S4.3. Analysis of Engine efficiency vs RPM

Thermal efficiency can be calculated by the following formula:

$$\text{Efficiency} = \text{Useful work done} / \text{Heat provided} \tag{S12}$$

Table S15. Engine efficiency vs RPM of Stirling engine.

| S No | Temp diff (°C) | Bronze - Max efficiency (%) |
|------|----------------|-----------------------------|
| 1 | 20 | 0.017 |
| 2 | 25 | 0.025 |
| 3 | 30 | 0.026 |
| 4 | 35 | 0.031 |

Table S16. Engine efficiency vs RPM of Stirling engine.

| S No | Temp diff (°C) | Bronze - Max efficiency (%) |
|------|----------------|-----------------------------|
| 1 | 20 | 0.02 |
| 2 | 25 | 0.024 |
| 3 | 30 | 0.03 |
| 4 | 35 | 0.035 |