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# A Review on Advancement of Nitinol Heat Engine Model

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**Abstract—***Nitinol Heat Engine a useful invention which converts low-grade heat energy into work output. Low-grade heat is a major source of energy that remains untapped. Unlike other heat engines, this engine operates at low temperature. This paper presents the Basic Nitinol Heat Engine Model and the advancement which had been taken place in the field of design. New models of Nitinol Heat Engines were invented from the past history in recent years with a motive of the optimum model which has fewer limitations and high efficiency. This paper gives the overview of important modifications in Nitinol Heat Engine model which were gifted to society. Finally, some suggestions are given for these models in order to further utilize in practical applications.*

## 1. INTRODUCTION

### (A) Nitinol.

An alloy of Nickel & Titanium [1], [14], is a material that possesses unique physical & metallurgical properties. It is also called Shape Memory Alloy. It can be trained to memorize required shape. The material can be deformed plastically below its critical temperature & when this material subjected to a proper thermal condition, it returns to its memorized shape. This shape change comes during solid phase transformation i.e state of material remain same (solid) but phase structure change (martensitic to austenitic). Martensitic phase is low temperature, having low strength whereas austenitic phase is high temperature, having high strength.

Besides its other properties, it contains two closely related properties [2], -

1- Super Elasticity.
2- Shape Memory Effect.

### I. Super Elasticity.

As the name indicates, Super Elasticity is the property of materials or alloys to recover large strain (up to 8%) cycle repeatedly without damaging the physical structure of materials and without permanent deformation. A large strain is possible by applying force. Super Elastic behavior of these materials takes place in a narrow range temperature.

In nitinol during loading, the strain is produced in stress-induced martensite, while heating results in the conversion of unstable martensite back to austenite with an immediate recovery of all the accumulated strain.

### II. Shape Memory Effect.

The Shape Memory Effect [6], is the ability of the materials or alloys to remember its pre-deformation shape.

When nitinol heated from some relatively low temperature to its critical temperature, solid phase transformation occurs from martensite to austenite phase. This transformation resulted in changing of deformed material shape to its initial pre-deformed shape.

### (B) Composition.

A Typical Nickel-Titanium[1], [2], [3], alloy contains 49 -57 % Nickle & rest is Titanium but the ideal composition of Nitinol can only vary between 38% to 50% Titanium by weight.

Variation in composition, effect its critical temperature (temperature require to convert from martensite phase to austenite phase) value.

| **Alloy composition** | |
|---|---|
| Weight percent nickel | Critical temp °C |
| 53.5 | 98 |
| 54.0 | 140 |
| 54.5 | 170 |
| 55.0 | 140 |
| 55.5 | 30 |
| 56.0 | -25 |
| 56.5 | -50 |

### (C) Properties-

| **Physical Properties** | |
|---|---|
| Appearance | Bright Silvery metal |
| Density | 6.45 gm/cm3 |
| Melting Point | 1310 °C |
| Resistivity<br>Austenite Phase<br>Martensite Phase | <br>82 ohm -cm<br>76 ohm -cm |

| | |
|---|---|
| Thermal Conductivity<br>Austenite Phase<br>Martensite Phase | <br>0.18 W/cm -°C<br>0.086 W/cm-°C |
| Heat Capacity | 0.332 J /gm |

| **Mechanical Properties** | |
|---|---|
| Young's Modulus<br>Austenite Phase<br>Martensite Phase | <br>83 GPa<br>28-41 GPa |
| Yield Strength<br>Austenite Phase<br>Martensite Phase | <br>195-690 MPa<br>70-140 MPa |
| Ultimate Tensile Strength (work hardened) | 1900 MPa |
| Poisson's Ratio | .33 |

| **Transformation Properties** | |
|---|---|
| Transformation Temp. | -200 - 110 °C |
| Transformation Strain<br>For single cycle<br>For 100 cycle<br>For 1,00,000 cycle | <br>8%<br>6%<br>4% |

**(D) Lattice Structure-**

The Transition from [2], [3], monoclinic crystal (fig.2) form (martensite) to ordered cubic crystal (fig.1) form (austenite) trigger the mechanism by which shape change occurs in SMA's.

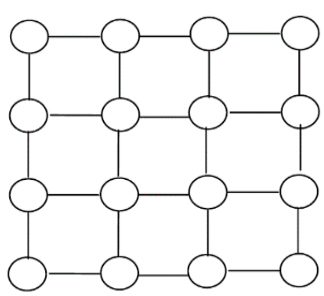

**Figure 1: Austenite (Cubic) structure (2-D) (High temperature)**

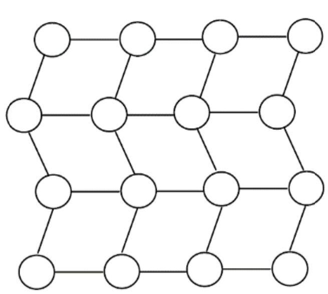

**Figure 2: Martensite (Twinned) monoclinic structure (2-D) (Low temperature)**

**(1) Deformation in ordinary metals-**

In ordinary metals, deformation takes place by dislocation phenomenon i.e. atomic planes sliding over one another by means of edge dislocation of screw dislocation, taking a new position in crystalline structure. Increase in complexity in dislocation planes will not allow the metals to reverse the deformation, thus resulting in permanent damage to the crystalline pattern.

**(2) Deformation in SMA-**

SMA's deform by detwinning (fig.3) (changing the tilt of twin orientation), which does not cause any movement of the plane of atoms or no dislocation of an atomic plane is happen.

At low temperature, in martensite phase atoms orient themselves in rows that are tilted left or right. This phenomenon is called twinning. In twinning, atoms from the mirror image of themselves or twins are formed. The martensite twins are able to flip their orientation to opposite tilt in a simple shearing motion cause detwinning. Detwinning is a shearing motion that allows the martensite phase to absorb dislocation, at some limit. Thus creating a co-operative movement of the individual twins. This result in a large overall deformation.

Heating this deformed martensite phase material trigger the atoms to reorient themselves in such a way that martensite lattice start to untilt and get in the austenite phase. Consequently, the original shape of the material is achieved at Critical temperature.

For complete shape recovery, the deformation process should not involve slip, because slip is an irreversible process.

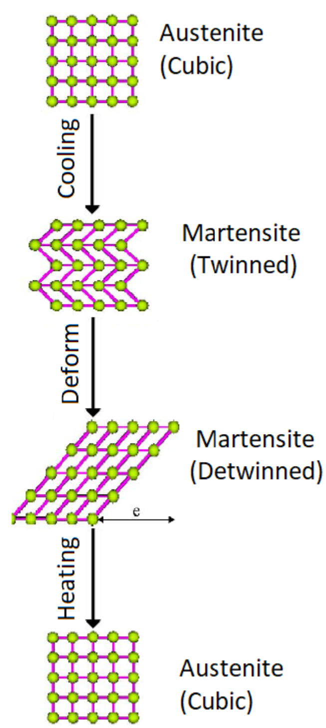


**Figure 3: Shape memory effect process.**

## 2. NITINOL HEAT ENGINE

The invention [12] of SMA's spurred intense interest in the field of the heat engine. Nitinol engines can use heat from low-temperature sources like solar heated water, geothermal hot water, rejected heat from conventional heat engine for conversion of power.

These engines functions as an energy conversion system, which use temperature difference reservoirs to convert heat energy to mechanical work. Unlike other conventional heat engines like gasoline or other fuel type engines, these heat engines do not require high combustion temperature. Also, working mechanism of these engines is different with other heat engines.

With the introduction of nitinol material in 1962, and in 1965 the mechanism to convert heat energy to mechanical work with the help of nitinol material is introduced.

### (A) Heat Engine by W.J Buehler & D.M Goldstein-

The earliest patent on the mechanism of conversion of thermal heat energy to mechanical work using nitinol was introduced by Buehler & Goldstein in 1968 (fig.4). [4], This model has very simple mechanism following properties of nitinol i.e. force applied for elongation is less than force resists for contraction. A less amount of force is required to deformed low temp. martensite phase nitinol whereas when the material critical temperature is reached, the large resistance force is applied by the material to retain its high-temperature austenite phase structure.

In this model, a Nitinol alloy strip supported at two ends, below its critical temperature. A weight is mount to deform the strip by some length when this deformation has happened, then an extra weight is applied to the strip and raise the temperature of the strip above its critical temperature. On attaining critical temperature, strip applies the resistance force to get back in its original shape.

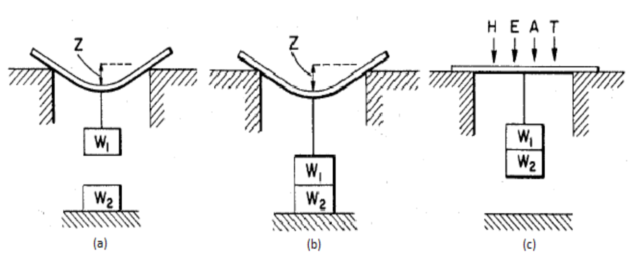


**Figure 4: Diagrammatic representation of Buehler & Goldstein**

### (B) Heat Engine by Ridgway M. Banks-

Ridgway M. Banks [5], [7], invented the first continuously operating heat engine using nitinol in 1973 (fig.5).

The construction is as follows, a flywheel shape like a wheel, contain a number of spokes, in which each spoke holding 2-nitinol wire loops suspended on both ends. The wheel hub is on an offset axis, due to this eccentricity when wire loop is contracted spoke is stretch more on one side of the wheel than on the other. Due to this stretching of spoke rotation of the wheel is possible This whole setup is set it into circular cylinder vessel which contains cold water on the half side and hot water on other half side separated by a wall in the middle.

On contact with hot water nitinol wire loop contract powerfully with a force of around 448 N/mm2, this force was able to turn the flywheel, on the other side on contact with cold water, they quickly gain their original shape and give free movement on other sides of the spoke.

Following disadvantage is occurs in this model, it has inefficient use of nitinol wire because deformation of the wire loop is in the discrete manner which provides fluctuation in power output also mechanical & thermal losses occur due to hydrodynamic friction.

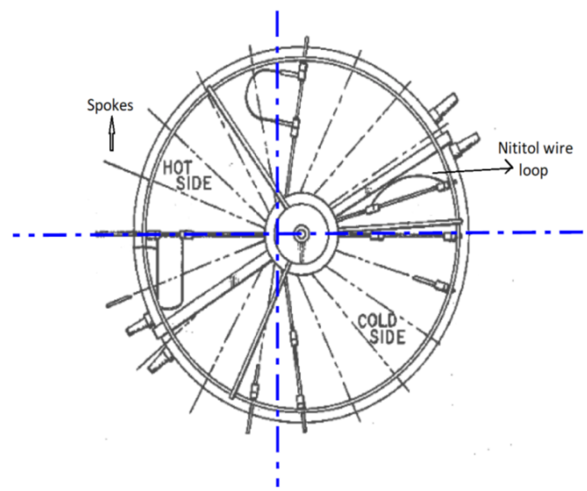


**Figure 5: Plane view of Ridgway's heat engine**

### (C) Heat Engine by Dante J. Sandoval-

Sandoval builds his first [8], engine model in 1977(fig.6). In this model simple two pulleys are used. One has a large diameter and other having a small diameter. Both pulleys are connected by a belt made of nitinol material. Smaller pulley is in contact with the hot source. When heat is given to belt at adjacent to smaller pulley circumference. Straightening force inherent in belt heated portion (fig.7). This straitening resistance force act as a pulling force to its adjacent belt portion cause rotation of belt and hence the pulleys.

This model has the disadvantage of slipping of the belt over pulley due to fact that physical structure of material change at circumference causing the belt to straighten and loose contact with the pulley. Hence reduce the efficiency of the model.

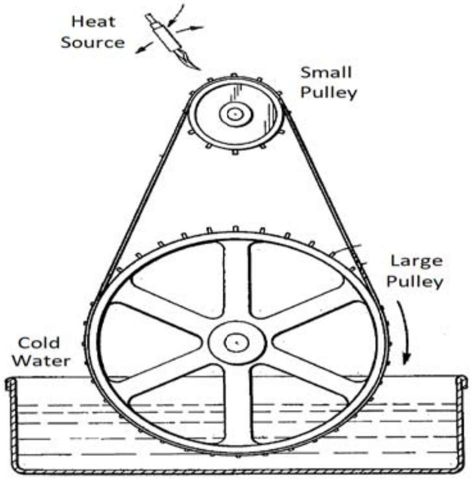


**Figure 6: Sandoval's heat engine**

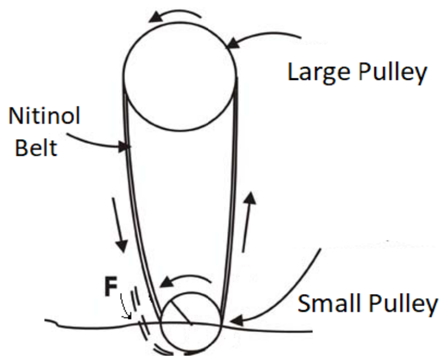


**Figure 7: Force apply by belt on contraction**

**(D) Heat Engine by Alfred Davis Johnson-**

Johnson [9], also builds his first continuously operating heat engine using nitinol, in 1977(fig.8).

The construction is as follows, SMA's wire in the form of helix-coil band mounted on a pair of grooved pulley having a small & large diameter. Grooved pulley compensates slipping phenomenon. The shaft of the pulley is mounted with same size gears which also connected with each other, allow same angular velocity by synchronizing them. This small and large dia. pulley connected to heat source and sink. An initial condition set by setting the large dia. pulley in the heat sink and smaller dia. pulley in the heat source.

The initial rotation makes the cold side wire (coil) to stretch and on the contrary hot side wire get contracts to its memory shape. Due to the difference in pulley dia. the different tension force is produced in the wire (coil) which result in a net torque on the large dia. pulley, which produces the power output.

Following disadvantage occurs in this model, due to its helix shape water is readily transported by the band. Affect heat transfer and mixing of reservoir fluid occurs during working.

As pulley is mounted in source and sink, during phase transformation of the band at the circumference of the pulley, due to stretching and contracting, slip phenomenon occurs.

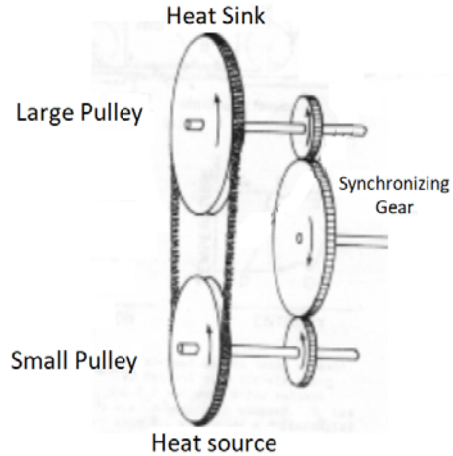


**Figure 8: Johnson's heat engine**

**(E) Heat Engine by J.J Patcher-**

John patcher builds his heat engine in 1979 (fig.9). This heat engine has similar working like Johnson but instead of helix coil, he uses straighten belt made of nitinol.

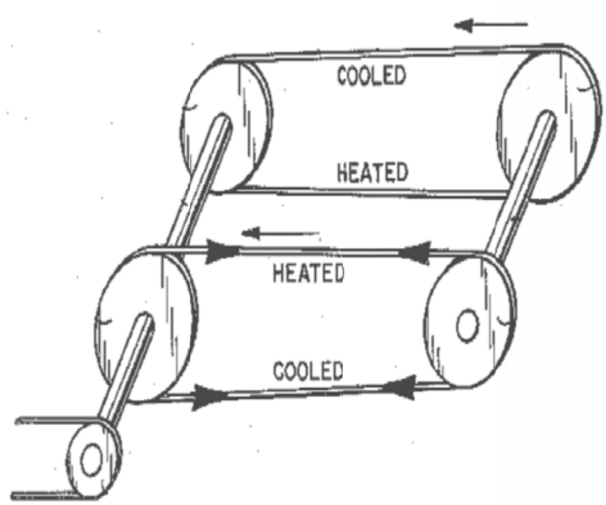


**Figure 9: Patcher's heat engine**

**(F) Heat Engine by Clarence M. Waymen-**

Waymen [10], build his continuously operating engine in 1981 . This engine working is also same as Johnson & Patcher engine, in this braided belt fabricated from nitinol wire is used(fig.10) . Through this braided belt, high friction & more power is achieved results in less slip.

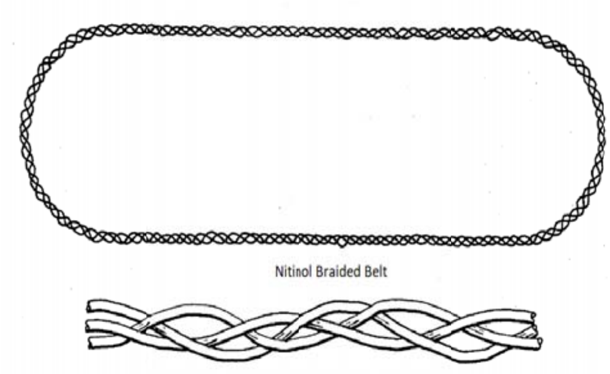


**Figure 10: Braided nitinol wire**

**(G) Heat Engie by D.M. Goldstein-**

In 1991 Davis M. Goldstein, [11], build a nitinol heat engine model (fig.11) having mechanism somehow similar to Sandoval engine.

In this, a thin sheet of nitinol material formed into a belt which on contraction formed into a zig-zag continuous pattern, contact at a spaced location with the pulley. One pulley is inserted in a thermal heating region in which portion of a belt with the pulley is inserted. When the belt is in contact with heat source it contracts in zigzag pattern, produce tension in remaining adjacent belt part. This result as an unbalanced force on pulley induce rotation thereof & movement of the belt. The belt expands as it moves out of the thermal heating region causing the pattern contraction to flatten out as the belt approaches the other pulley.

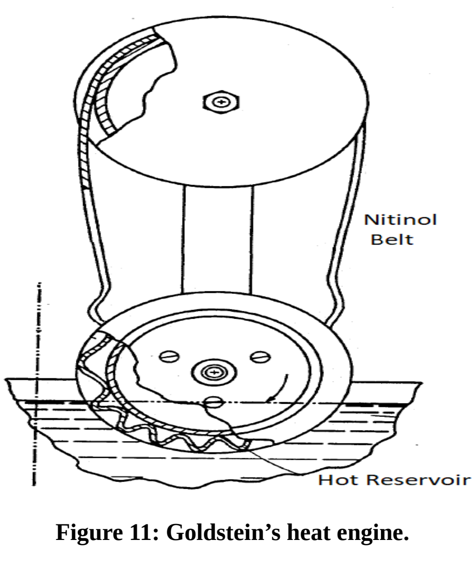


**Figure 11: Goldstein's heat engine.**

## 3. CONCLUSIONS & DISCUSSION

The initial part of this research paper reviews some of the theoretical backgrounds on SMA's. We saw that these materials memorize their shape at a specific temperature(400-500°C). At low temp, they are easy to deform, but at above critical temperature they exert large force as they try to recover their original shape.

This paper gives the detail past work that has been attempted in this area. It seems that the first model is not efficient to use on practical utility, however, several research had been done by researcher and invent some improvised model were invented. As the research go forward improvement has been done in this research area.

Apart from these, there are also some limitations in these models. These are given below –

(A) Skidding & elastic slip of band
(B) Large Friction losses
(C) Lower torque transmission
(D) Lifting of belt during solid phase change of material.

These limitations needs to improvise with future works so that a better engine model with fewer limitation is invented, which is useful to society. These heat engines is a great initiative to give work output with low-grade heat (100-150 °C) which is not properly utilized in our ecosystem.

## REFERENCES

[1] W.J. Buehler, R.C. Willey "TiNi-ductile Intermetallic Compound". Trans.Amer. Soc.Met., 55 (1), 269-276 (1962);

[2] Buehler, W. J.; Gilfrich, J. V. and Wiley, R. C.: Effect of Low-Temperature Phase Changes on the Mechanical Properties of Alloys Near Composition of TiNi, J. Appl. Phys., Vol. 34,1963, p. 1475-1477.

[3] Wiley, R. C.; Sutton, C. E., Stresses Associated with Structural Transformations in 55.4 NITINOL, Jan 24, 1964.

[4] Buehler, W. *3.* and Goldstein, D. M., "Conversion of Heat to Mechanical Energy," U. S. Patent 3,403,238, Sept. 1968.

[5] Ridgway M. Banks, Orinda, Calif "Energy Conversion System" U.S. Patent, 3,913,326, Oct. 21, 1975

[6] Banks, R., Nitinol Heat Engines, Shape Memory Efferts in Alloys, J. Perkins, Ed. Plenum Press, N.Y., 1975.

[7] Banks, R.; Wahlig, M., NITINOL Engine Development LBL-5293,ERDA Contract W-7405-ENG-48 International Solar Energy Society Meeting, Winnipeg, Canada, August 1976.

[8] Dante J. Sandoval, 6412 Pear Ave., Cleveland, Ohio 44102, " Thermal Moter" U.S. Patent, 4,030,298, June 21,1977

[9] Johnson, A. D., "Memory Alloy Heat Engine and Method of Operation "U. S. Patent 4,055,955, Nov. 1977

[10] Clarence M. Wayman, Urban "Solid State Thermal Engine" U.S Patent 4,246,754, Jan 27, 1981

[11] David Goldstein, Adelphi,Md " Heat Engine With Corrugated Shape Memory Drive Belt", U.S. Patent 4,996,842, march 5,1991

[12] Schetky MHWaLM. Industrial Applications for Shape Memory Alloys. Proceedings of the International Conference on Shape Memory and Superelastic Technolgies. Pacific Grove, California2000. p. 171-82.

[14] Lagoudas DC. Shape Memory Alloys: Springer US; 2008