Technical Characteristics of

Actuator Wire is known by a number of names muscle wire – Shape memory alloy, Smart wire and nitinol wire

Actuator Wires (are small diameter wires which contract like muscles when electrically driven. Smaller than motors or solenoids, cheaper and generally easier to use, these wires perform physical movement across an extremely wide variety of applications.

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Section 1.   Movement

The movement or stroke of the actuator (muscle wire)is measured as a percentage of the length of the wire being used and is determined, in part, by the level of stress one uses to reset the wire, or to stretch it in its low temperature phase. This opposing force, used to stretch the wire, is called the bias force. In most applications, the bias force is exerted on the wire constantly, and on each cycle as the wire cools, this force elongates it. If no force is exerted as the wire cools, very little deformation or stretch occurs in the cool, room temperature state and correspondingly very little contraction occurs upon heating. Up to a point the higher the load the higher the stroke. The strength of the wire, its pulling force and the bias force needed to stretch the wire back out are a function of the wire size or cross sectional area and can be measured in pounds per square inch or “psi”. If a load of 5,000 psi (34.5 MPa) is maintained during cooling, then about 3% memory strain will be obtained. At 10,000 psi (69 MPa), about 4% results, and with 15,000 psi (103 MPa) and above, nearly 5% is obtained. Possytronics muscle wire has a movement of approximately 5% However, there is a limit to how much stress can be applied.
Far more important to stroke is how the wire is physically attached and made to operate. Dynamics in applied stress and leverage also vary how much the actuator wires move. While normal bias springs that increase their force as the actuators contract have only 3-4% stroke, reverse bias forces which decrease as the actuator wires contract can readily allow the wire to flex up to 7%. Mechanics of the device in which it is used can convert this small stroke into movements over 100% of the wires' length and at the same time provide a

reverse bias force. The stress or force exerted by actuator wires is sufficient to be leveraged into significant movement and still be quite strong. Some basic structures, their percent of movement, and the approximate available force they offer in different wire sizes are as follows:

Muscle wire, also known as smart wire, actuator wire more commonly known as nitinol wire, which is the name for very high performance, shape memory alloy, actuator wires. It is made of nickel-titanium

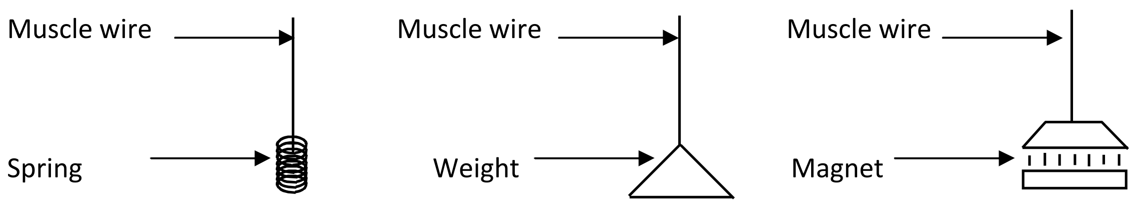
NI - Nickel. **TI -** Titanium. **NOL -** Naval Ordnance Laboratory. **NITINOL**

These small diameter wires have been specially processed to have large, stable amounts of memory strain for many cycles. In other words they contract like the fibres of a human muscle, when electrically driven (hence the name muscle wire)

The ability to shorten in length approximately 5% occurs because both nickel and titanium atoms are present in the alloy in almost exactly a 50% 50% ratio which dynamically change their internal structure at certain temperatures. The idea of reaching higher temperatures electrically came with the light bulb, but instead of producing light these alloys contract by 4 to 5% of their length when heated and can then be easily stretched out again as they cool back to room temperature.

Stretching muscle wire to its original length can be achieved by the use of a spring or small weight

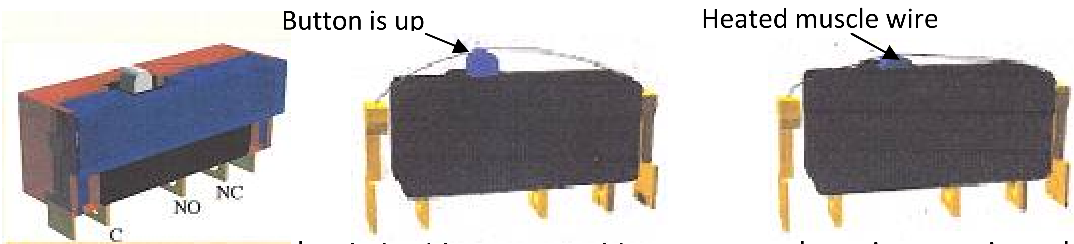
(**This opposing force, used to stretch the wire to its original state, is called the bias force**)



Normal Bias Spring **Dead Weight Bias** **Magnet Bias**

The main point is that movement occurs through an internal "solid state" restructuring in the material that is silent smooth, and powerful.

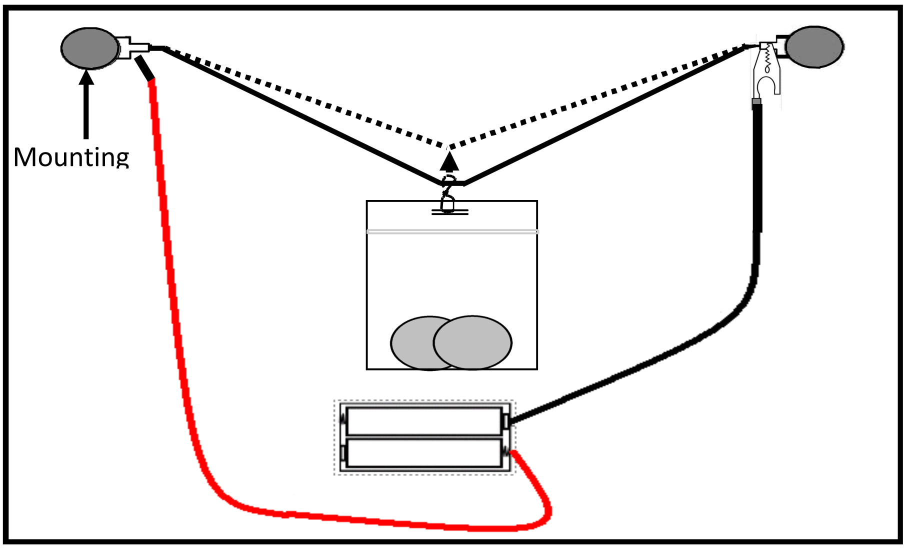
Many of the tasks currently being done with small motors or solenoids can be done with muscle wire, which are smaller and less expensive. A simple relay can be achieved as shown below.



A simple add on to a standard switch, this cover enables one to make a inexpensive relay, by holding muscle wire in place over the push button, when the wire is heated it will contract 5% and activate the switch as shown above.

Section 2. Electrical Guideline

All Possytronics Muscle wires 100mm and 150mm work with 3v supply as Shown below



But a simple rule can be applied to prevent overheating, by observing the muscle wire when the current is shut off, the wire should immediately begin to cool and relax to its original length. If it does not begin to relax and elongate under a small bias force when the power is cut, then the wire has been needlessly overheated. **Simple visual observation is all that is needed to prevent overheating**

If actuator wire (muscle wire) is used within the guidelines then obtaining repeatable motion from the wire for tens of millions of cycles is reasonable. If higher stresses or strains are imposed, then the memory strain is likely to slowly decrease and good motion may be obtained for only hundreds or a few thousand of cycles. The permanent deformation, which occurs in the wire during cycling, is heavily a function of the stress imposed and the temperature under which the actuator wire is operating. Actuator wire has been specially processed to minimize this straining, but if the stress is too great or the temperature too high some permanent strain will occur. Since temperature is directly related to current density passing through the wire, care should be taken to heat, but not overheat, the actuator wire. The following chart gives rough guidelines as to how much current and force to expect with various wire sizes.

Diameter Size (mm)	Resistance (ohms/m)	Pull Force* (grams)	Approximate** Current at Room Temperature (mA)	Contraction** Time (seconds)	Off Time 70° C "LT" Wire*** (seconds)	Off Time 90° C "HT" Wire*** (seconds)
0.025	1424.8	8.9	45	1	0.18	0.15
0.038	889.5	20.0	55	1	0.24	0.20
0.050	500.0	35.6	85	1	0.4	0.3
0.076	232.2	80.2	150	1	0.8	0.7
0.102	126.0	142.5	200	1	1.1	0.9
0.127	74.8	222.7	320	1	1.6	1.4
0.152	55.1	320.6	410	1	2.0	1.7
0.203	29.1	570.0	660	1	3.2	2.7
0.254	18.5	890.6	1050	1	5.4	4.5
0.305	12.2	1282.5	1500	1	8.1	6.8
0.381	8.3	2003.9	2250	1	10.5	8.8
0.508	4.3	3562.6	4000	1	16.8	14.0

The pulling force is based on 172 MPa, which for many applications is the maximum safe stress for the wire. However, many applications use higher and lower stress levels. This depends on the specific conditions of a given design.

** The contraction time is directly related to current input. The figures used here are only approximate since room temperatures, air currents, and heat sinking of specific devices vary. On small diameter wires (</= 0.152mm diameter) currents which heat the wire in 1 second can typically be left on without over-heating it. Both heating and cooling can be dramatically changed

*** Approximate cooling time, at room temperature in static air, using a vertical wire. The last 0.5% of deformation is not used in these approximations. LT = Low Temperature and HT = High Temperature Actuator wire.

Section 3. Cycle Time

The contraction of the actuator wire is due solely to heating and the relaxation solely to cooling. Both contraction and relaxation are virtually instantaneous with the temperature of the wire. As a result mechanical cycle speed is dependent on and directly related to temperature changes. Applying high currents for short periods of time can quickly heat the wire. It can be heated so fast in fact that the limiting factor is not the rate at which heating can occur but rather the stress created by such rapid movement. If the wire is made to contract too fast with a load, the inertia of the load can cause over stress to the wire. To perform high speed contractions inertia must be held low and the current applied in short high bursts. Naturally, current which will heat the wire from room temperature to over 212 °F (100°C) in 1 millisecond, will also heat it much hotter if left on for any length of time.

While each device has quite different heat sinking and heating requirements, a simple rule of thumb test can be used to prevent overheating. Measuring the actual internal temperature of the wire across such short time periods is somewhat problematic, however, one can tell if the actuator wire is overheated simply by observing if the wire immediately begins to cool and relax when the current is shut off or not.

If it does not begin to relax and elongate under a small load promptly, when the power is cut, then the wire has been needlessly overheated and could easily be damaged. Simple visual observation is all that is needed to design measured heating circuitry.

Actuator wire (Muscle wire)has a high resistance compared to copper and other conductive materials but is still conductive enough to carry current easily. In fact one can immerse the wire in regular tap water and enough current will readily flow through it to heat it. All of the conventional rules for electrical heating apply to the wire, except that its resistance goes down as it is heated through its transformation temperature and contracts. This is contrary to the general rule of increased resistance with increased temperature. Part of this drop in resistance is due to the shortened wire, and part is due to the fact that the wire gets thicker as it shortens, roughly maintaining its same three-dimensional volume. It makes no difference to the wire whether alternating current, direct current, or pulse width modulated current is used.

Again relaxation time is the same as cooling time. Cooling is greatly affected by heat sinking and design features. The simplest way to improve the speed of cooling is to use smaller diameter wire. The smaller the diameter the more surface to mass the wire has and the faster it can cool. Additional wire, even multiple strands in parallel, can be used in order to exert whatever force is needed. The next factor in improving the relaxation or cooling time is to use higher temperature wire. This wire contracts and relaxes at higher temperatures. Accordingly the temperature differential between ambient or room temperature and the wire temperature is greater and correspondingly the wire will drop below the transition temperature faster in response to the faster rate of heat loss.
Other methods of improved cooling are to use: forced air, heat sinks, increased stress (this raises the transition temperature and effectively makes the alloy into a higher transition temperature wire), and liquid coolants. Combinations of these methods are also effective. Relaxation time can range from several minutes (i.e. delay switches) to fractions of milliseconds (i.e. miniature high speed pumps) by effective and proper heat sinking. The following page gives some idea of the effect these various methods have.

Section 4. Underlying Technology

A very high performance, shape memory alloy, actuator wires. Made of nickel-titanium these small diameter wires have been specially processed to have large, stable amounts of memory strain for many cycles. In other words, they contract like muscles when electrically driven.

This ability to flex or shorten is characteristic of certain alloys that dynamically change their internal structure at certain temperatures. Actuator wires contract by several percent of their length when heated and then easily elongate again by a relatively small load when the current is turned off and they are allowed to cool.

The function of the actuator wire is based on the shape memory phenomenon which occurs in certain alloys in the nickel-titanium family. When both nickel and titanium atoms are present in the alloy in almost exactly a 50%/50% ratio, the material forms a crystal structure which is capable of undergoing a change from one crystal form to another (a martensitic transformation) at a temperature determined by the exact composition of the alloy. In the crystal form that exists above the transformation temperature (the austenite) the material is high strength and not easily deformed. It behaves mechanically much like stainless steel. Below the transformation temperature, though, when the other crystal form (the martensite) exists, the alloy can be deformed several percent by a very uncommon deformation mechanism that can be reversed when the material is heated and transforms. The low temperature crystal form of the alloy will undergo the reversible deformation fairly easily, so the "memory" strain can be put into the material at rather low stress levels.

The resultant effect of the shape memory transformation of the Actuator wire is that the wire can be stretched about 4-5% of its length below its transformation temperature by a force of only 10,000 psi (69 MPa) or less. When heated through the transformation temperature, the wire will shorten by the same 4-5% that it was stretched, and can exert stresses of at least 25,000 psi (172 MPa) when it does so. The transformation temperature of the NiTi alloys can be adjusted from over 212 °F (100°C) down to cryogenic temperatures, but the temperature for the Flexinol® actuator wire has been chosen to be 140 –230 °F (60 - 110 °C). This allows easy heating with modest electrical currents applied directly through the wire, and quick cooling to below the transformation temperature as soon as the current is stopped.

Heating with electrical current is not required, but it is perhaps the most convenient and frequently used form of heat.

Actuator wires' prime function is to contract in length and create force or motion when it is heated. There are limits, of course, to how much force or contraction can be obtained. The shape memory transformation has a natural limit in the NiTi system of about 8%. That is the amount of strain that can occur in the low temperature phase by the reversible martensitic twinning which yields the memory effect. Deformation beyond this level causes dislocation movement throughout the structure and then that deformation is not only non-reversible but degrades the memory recovery as well. For materials expected to repeat the memory strain for many cycles, it is best to utilize a cyclic memory strain of no more than 4-5%, and that is what is recommended with actuator wire.

The force that the actuator wire can exert when heated is limited by the strength of the high temperature austenitic phase. The phase transformation, or crystal change, that causes the memory effect has more driving force than the strength of the parent material, so one must use care not to exceed that yield strength. The yield strength of actuator high temperature phase is over 50,000 psi (345 MPa), and on a single pull the wire can exert this force. To have repeat cycling, however, one should use no more than 2/3 of this level, and forces of 20,000 psi (138 MPa) or below give the best repeat cycling with minimal permanent deformation of the wire

Sample Application for Muscle Wire

(also known as nitinol wire, smart wire, actuator wire)

Electronics

Retrofit Switch to Relay (as shown P4)
Safety Cut Offs
“Clean” Actuators
Micro Circuit Breakers
Remote Switch Controllers
PC Mount Relays
Chassis Temp Controls
Mechanical Latches
Electronic Locks
Subminiature Door Openers
Micro Clutches
Spring loaded Releases

Automotive

Environmental controls
Door Locks
Mirror Controls
Remote release
Gear changing Trigger
Pneumatic Valve
Alarms
Motor Protectors

Medical

Surgical Instruments
Prosthetic Limbs
Remote Latches
Steerable Catheters
Blood Pressure Test Valves
Exoskeletal Assistance
Vacumn Test Manipulators
Micro Pumps

Miscellaneous

Smart materials
Robotic limbs
Alarm Devices
Light Fibre Switches
Ultralight Remote Control
Mechanical Scanners