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APPLICATIONS OF SHAPE MEMORY IN THE USA

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Abstract

A listing of all the prototype devices to use shape memory would be most impressive in its variety, but the real test for a new idea is its commercial success. This paper will summarize the applications of shape memory that are currently in production in the United States, with the emphasis upon new applications.

1. COUPLINGS

The first commercially successful application of shape memory was as hydraulic couplings for the Grumman F-14 (Figure 1). Now, after 1.5 million installations without a single reported in-service failure, nearly all new military aircraft have specified Ni-Ti couplings as the only permissible system for joining hydraulic lines. Without question, these couplings have been the most successful application of shape memory in the world today. Their success appears to be a result of their simplicity: they consist of a monolithic cylinder, expected to recover only once. They are expanded in liquid nitrogen, and begin to recover at -100°C, with recovery complete well before room temperature is reached, so no heating tools are required. Teeth machined on the coupling ID bite into the tube forming a metal-to-metal seal, and a tapered tail coated with a polymeric compound provides strain relief and the necessary fatigue performance.

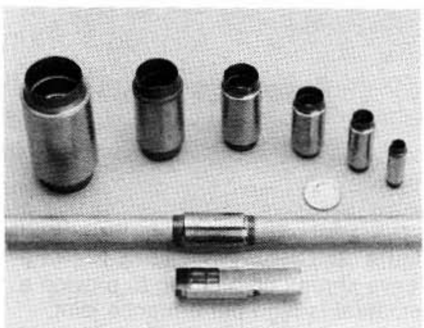

Figure 1: Ni-Ti-Fe Cryofit® aircraft hydraulic couplings have been in production since 1969.

Although liquid nitrogen storage is not an issue for most large aircraft manufacturers, there are applications for which cryogenics are impractical. One of the most recent developments is that of a new line of couplings that can be stored and installed at room temperature, and heated to cause recovery. This is made possible by the use of a new Ni-Ti-Nb alloy with a very wide hysteresis, so that installed parts remain austenitic well below room temperature.

A second development during the last year is that of the Cryolive® demateble coupling system. The sealing arrangement is shown in Figure 2: only the olive shaped sleeve is Ni-Ti. This sleeve is shrunk onto the tube to form a metal-to-metal seal, and a nut then compresses and seals the outside of the sleeve to a union. In the past, sleeves have been installed by internal swaging: a costly and cumbersome process.

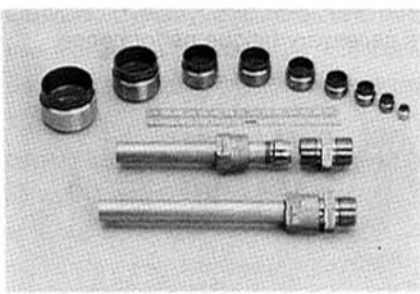

Figure 2: Cryolives® use a Ni-Ti-Fe sleeve shrunk unto tubing to provide a demateable high performance joint.

Couplings for the marine and commercial markets take on quite a different appearance from aircraft couplings simply because cost becomes a more important factor than weight savings. Figure 3 shows the various configurations now in production. From left to right are a monolithic Ni-Ti coupling, a driver-liner design offering superior galvanic compatibility with pipe materials, a ring-body design which provides the opportunity to make fittings of complex shape, and a Permacouple® consisting of a Cu-Zn-Al-Mn sleeve around an aluminium sleeve with an inside coating of epoxy.

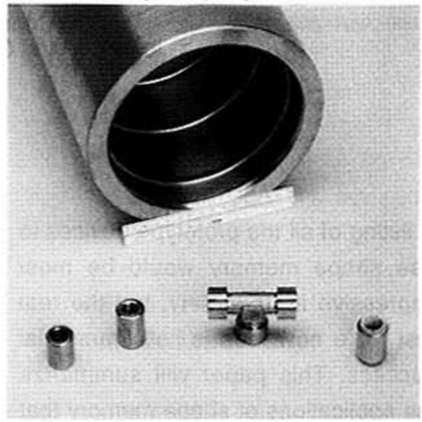

Figure 3: The four basic types of marine coupling are shown in front of the largest coupling ever made: a Ni-Ti-Fe coupling used for joining 15 mm diameter subsea gas lines.

2. FASTENERS

Fasteners are also a joining applications, but unlike couplings, hermetic sealing may not be required. The most successful example of a fastener is the Ni-Ti-Nb Tinel Lock® ring used to fasten braided shielding to the back of a connector (Figure 4). Although there are other approaches to solving this problem, memory rings provide the greatest mechanical and electrical integrity. Other fastener applications range from large rings to join segments of missiles, to small rings to locate bearings on a shaft.

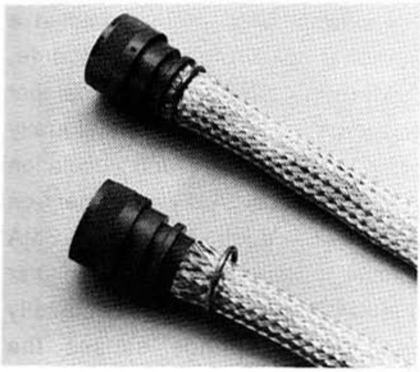

Figure 4: Welded Ni-Ti-Nb wire rings are shrunk onto copper braid by electrical resistance heating.

3. ELECTRICAL CONNECTORS

The first SMA connector device was the Cryocon® (Figure 5), consisting of a series of Cu-Be fingers pushing out against a Ni-Ti-Cu ring. At room temperature, the austenitic ring overpowers the Cu-Be and constricts against a pin, forming a highly vibration resistant and reliable connection; when cooled with freon, the Cu-Be fingers push the ring open and release the pin. This device can be mated and demated several hundred times without degradation.

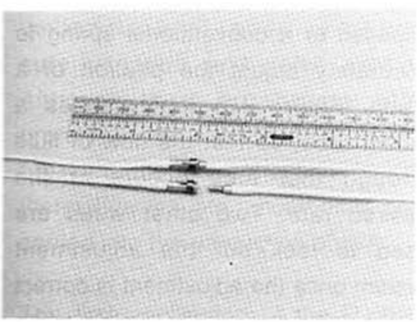

Figure 5: The Cryocon® was the first ZIF (Zero Insertion Force) connector to use shape memory.

The second design to be introduced is the Cryotact® (Figure 6) and is very similar to the Cryocon®, though less expensive, able to accommodate larger tolerances in pin size and more resistant to overheating. These devices are usually linearly grouped to form Dual In-line Package (DIP) connectors.

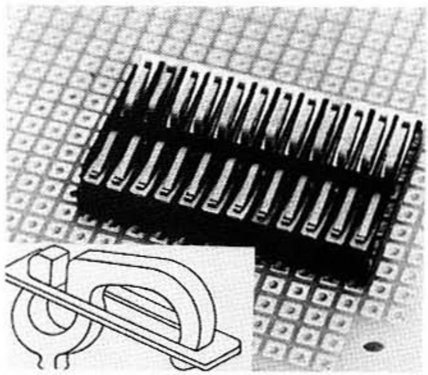

Figure 6: DIP connectors use a stamped rectangular Ni-Ti-Cu ring working against a Cu-Be socket, with the socket opening at -60°C.

The next connector design consisted of a guillotine, in which a shape memory element causes two grids slide across one another constricting against a grid of pins (Figure 7). These Pin Grid Array Package (PGAP) connectors provide very high pin retention force with zero insertion force and unlike soldering are convenient for removal and reinstallation.

The newest connector is the Betaflex® connector (Figure 8) in which a memory element is heated to push against a C-shaped spring and release a flexible polyimide connector strip. Some advantages of this sort of approach are a lower cost per line, a higher density of contacts, and that no freon or liquid nitrogen are used.

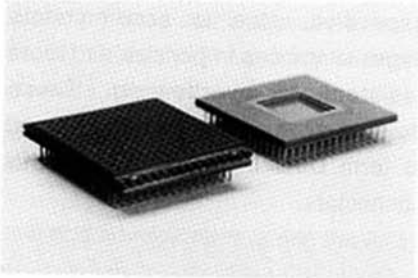

Figure 7: A Pin Grid Array Package and SMA connector.

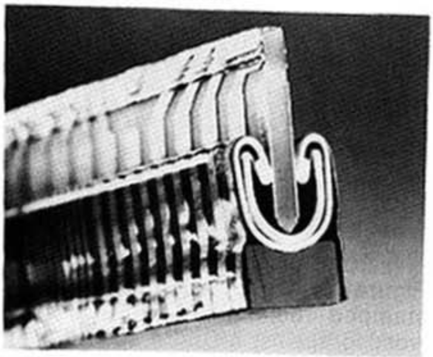

Figure 8: The Betaflex® connector differs from previous designs in that in is heated to release contact. (courtesy of Betaphase)

4. ELECTRICAL ACTUATORS

The first marketed electrical actuator unit was VEASE®, a self contained unit with a Ni-Ti spring, biasing return spring, and an overload protection device to prevent the memory spring from damaging itself should motion be temporarily prevented. VEASE was originally used to open the louvres of an automobile fog lamp, but it has since become apparent that a generic actuating device would probably not be successful, and that SMA would be better applied through simple designs specific to the task being done.

The newest SMA product (called a Personal Environmental Module, PEM) uses 4 SMA springs as damper actuators. The PEM individually controls temperature and circulation in an office cubicle. Two dampers on the device each have two SMA springs working against one another (Figure 7); alternately electrically heating the springs causes the dampers to either open or close.

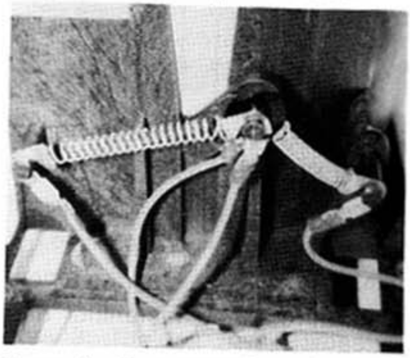

Figure 9: Two opposing electrically activated Ni-Ti springs are used to adjust damper position (courtesy of Johnson Controls, Inc.)

Another production actuator is the SMArt Clamp®: an intravenous fluid control device employing three short lengths of Ni-Ti wire. One wire is opposed to a conventional spring to accurately adjust the postion of a blade (Figure 10) that pinches a rubber tube, so that the flow of fluid through that tube occurs at the desired rate. Two other wires are used to lock out the adjustment system once the adjustment is correct and to again engage the system when re-adjustment is needed.

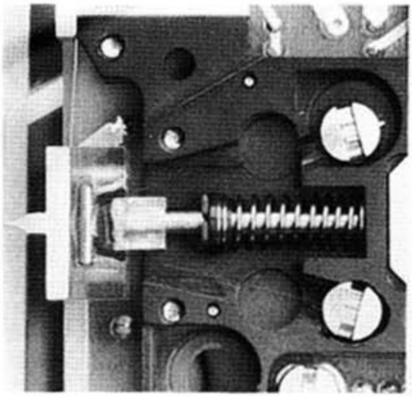

Figure 10: The SMArt Clamp® controller uses a Ni-Ti wire working against a helical steel spring to adjust the position of a contricting blade (left). (courtesy of Betaphase)

5. THERMAL ACTUATORS

The newest example of a thermal actuator in the USA is the anti-scald shower valve (Figure 11). Here a Cu-Zn-Al spring shuts off water flow before the water temperature becomes scalding. The spring does not directly close a valve, but just slightly moves a ball into the water stream, causing an instability in the flow, which then carries the ball to a blocking position. This ingenious method of decoupling the memory device from the water flow removes the difficulties of correcting for pressure variation and valve erosion. Although there are several other prototype thermal actuators (circuit breakers, thermal protection devices, thermal valves, etc.), none have been carried into the production phase.

The first application of the R-phase was the Thermobile®, a nifty demonstration heat engine taking advantage of the change in modulus associated with the R-phase transition (Figure 12). In this case, a Ni-Ti-Co alloy was used, the purpose of the Co being to separate the R-phase and martensite transformations.

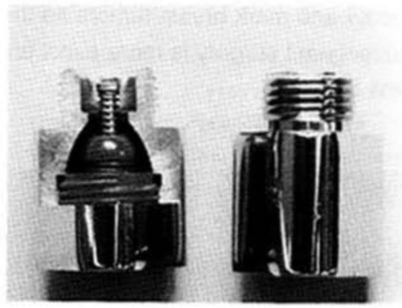

Figure 11. A Cu-Zn-Al spring in an antiscald shower valve prevents scalding. (courtesy of Memry Inc.)

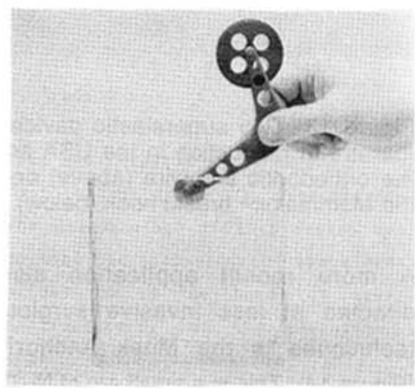

Figure 12: The Thermobile® from Innovative Technologies uses the R-phase to demonstrate principles of heat engines.

6. SUPERELASTICITY

The first superelastic application was as orthodontic archwire (Figure 13). The biggest advantages that Ni-Ti provides over conventional materials are an increased elastic range (reducing the need to retighten and adjust wires) and a nearly constant stress during unloading (tending to decrease treatment time and increase patient comfort). The second successful superelastic application was the Mammelok® breast hook (also shown in Figure 13) used to locate and mark breast tumors so that subsequent surgery is more exact and less invasive.

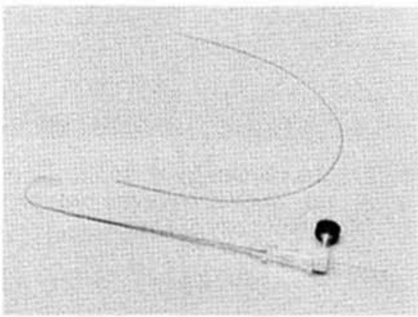

Figure 13: Two superelastic devices that are in production in the USA are the orthodontic archwire (above) and the Mammelok® breast hook (below).

A more recent application also directed at less invasive surgical techniques is the Mitek Anchor® (Figure 14). This is a small arc of Ni-Ti which is injected thought a cannula into a hole drilled into the bone; once free of the cannula it springs back to its arc configuration and anchors itself into the bone. A suture tied to the anchor is then used to re-attach ligaments to the bone. This device is has proven to lead to significantly faster patient recoveries.

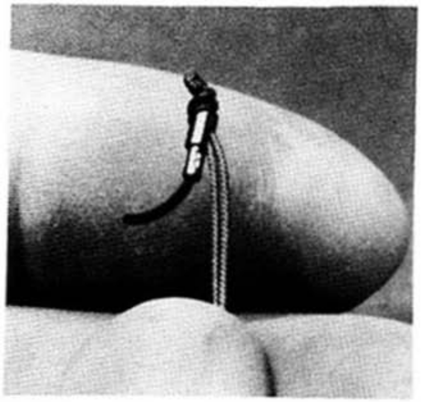

Figure 14: The newest pseudoelastic application is a Mitek Anchor® used to make ligament reattachment surgery less invasive.

7. SUMMARY

The shape memory industry in the United States has grown substantially in the last few years; there are now at least 4 commercial producers of shape memory alloys and 10 companies involved in new product development. Most of the emphasis is in the Ni-Ti based alloys, with ternary alloys of Ni-Ti-Fe, Ni-Ti-Nb, and Ni-Ti-Cu being the most successful. When one considers that the entire technological basis of shape memory is less than 25 years old, commercial growth has been remarkable, and all indications are that it will continues to be so.