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Low Melting Temperature Alloy Deployment Mechanism and Recent Experiments

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ABSTRACT

This paper describes the concept of a low melting temperature alloy deployment mechanism, U.S. Patent 4,842,106. It begins with a brief history of conventional dimethyl-silicone fluid damped mechanisms. Design fundamentals of the new melting alloy mechanism are then introduced. Benefits of the new over the old are compared and contrasted. Recent experiments and lessons learned complete this paper. We find this mechanism to be particularly promising, and may soon be recommending its use. A demonstration unit is powered-up to visually illustrate the deployment.

INTRODUCTION

Spacecraft are launched with a variety of large payloads which are folded or stowed to minimize envelope and to withstand launch loads. In general, these structures are weight optimized and delicate. It is necessary to limit their rate of deployment during the mission to prevent damage. Deployment rate can be rigidly controlled by using a motor drive or simply limited by providing a damping feature on a spring or centrifugally driven deployment. This is generally provided by coulomb, viscous, or eddy current damping. While these methods have all been employed with varying degrees of success, all have significant drawbacks. Motor drives are complex mechanical assemblies which require special drive electronics. Coulomb damping or friction typically leads to a very small torque or force margin which jeopardizes the success of the deployment. Eddy current dampers can be as complex as motorized drives. Viscous dampers are moderately complex and create a potential source of contamination if leakage were to occur. All methods have narrow performance ranges, require some sort of launch lock to restrain the payload during launch, and are typically faced with backlash, latching and stiffness problems.

Hughes Space and Communications has been a leader in spacecraft production for more than 25 years. A family of over fifteen different spring driven, rotary, viscous damped deployment mechanisms has evolved over the years. Over 100 units have been built and more than 60 have provided successful mission

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deployments. These mechanisms have a perfect track record - no mission failures! Despite this impressive record, a low melting temperature alloy deployment mechanism is an attractive and exciting development which offers many advantages.

DESIGN PHILOSOPHY

First, consider our traditional dimethyl-silicone fluid filled damper found in Figure 1. The cylindrical housing contains a pair of internal opposing teeth. The shaft boasts a pair of associated opposing paddles. Caps complete with o-rings and bearings seal off the ends. All gaps around the moving paddle are very closely controlled. The main radial gap determines the damping rate, as all other parasitic gaps are held as small as possible. Constant force springs (not shown) supply the driving torque for the mechanism. When the driving torque is applied, the fluid is forced to flow from the high pressure side of the paddles to the low pressure side. The viscous shear resistance developed in the process results in a slow, damped movement. Deployment continues until stops are reached. During the mission, thermal expansion and contraction of the fluid is accommodated by a spring-loaded o-ring sealed piston reservoir arrangement.

Now, take this traditional unit and alter it into the low melting temperature alloy damper, shown in Figure 1A. Remove one paddle from the shaft, and the related tooth from the housing. Discard the temperature compensation assembly. Keep the same bearings, o-rings, and end caps. Open all the gaps to be very generous. Fit a heater to the paddle. Replace the fluid with the alloy. In this arrangement, when a driving torque is applied, nothing happens until heat is selectively put to the paddle. When deployment is desired, heaters are powered-up, warming the shaft paddle and it slowly sweeps its way through the melting alloy like a hot knife through butter. Melt rate is controlled by heater power compared to the energy required to melt the alloy. Deployment continues until hard structural stops are reached. Once heater power is terminated, the alloy solidifies and the rigid joint configuration is recovered.

BENEFITS

This is a logical development of the existing viscous damping technology used extensively at Hughes, and the benefits of this device are overwhelming.

- Stiffness improvements are remarkable, since the alloy freezes whenever power is off.
    - zero backlash is achieved
    - no latches are required

- Complexity is reduced, since there are fewer parts.
    - tolerances open up

- design, assembly, and fill are easy
- bearings may not be needed
- clean room assembly is obsolete
- no need for highly-filtered fluid
- cost savings are dramatic

- Low shock situation is achieved, since explosive launch locks are unnecessary.

Other significant advantages are:

- larger deployment angles are available
- temperature compensation is unnecessary
- phased, sequential deployments are possible
- less dependency on bulk unit temperature
- single design provides a range of deployment rates
- modeling of complex non-Newtonian fluid not required

A summary comparison chart of new vs old and its benefits can be seen in Table 1.

DEVELOPMENTS

The engineering model of the first Hughes viscous damped actuator was built in 1976 and provided rate control for the deployment of the omni-directional antenna on the HS-376 satellite. In 1986 this unit was disassembled, fitted with a conventional heater, and filled with a low melting temperature alloy. The mechanism has been repeatedly cycled at presentations to demonstrate the concept and has shown no signs of degraded performance. No performance testing has been conducted with this mechanism. A patent application was filed in 1987 based on this device, and a United States patent was awarded in 1989; patent number 4,842,106, Rate Controllable Damping Mechanism.

Hughes is now in the process of testing a second generation engineering model unit, patterned after the new family of HS-601 deployment mechanisms.

The fluid-filled HS-601 Solar Wing Actuator is shown in Figure 2, and the as-tested melting alloy version of that unit is shown in Figure 2A, Figure 3 and Figure 4. The modified unit is of simplified design for ease of test. The following items were test plan performance objectives:

- foil heaters vs. cartridge heater at similar power levels
- different power levels
- same power level, but different allocation
- eutectic vs. non-eutectic alloy

- resistive torque vs. angle
- stiffness

RESULTS

Figure 5 illustrates that for the shaft, a cartridge heater arrangement is slightly more efficient than foil heaters. This efficiency increased the deployment rate near the end of deployment. Figure 6 results are obvious; namely that higher power level produces a faster deployment. Figure 7 power allocation curves show that if a steady deployment rate is desired, then power should be biased to the housing heaters. Some efficiency is lost, and deployment time increases. Figure 8 shows that there is no deployment rate distinction between the use of eutectic vs. non-eutectic alloys. Resistive torque tests were performed at various speeds, and consistent resistance readings indicate that there are no viscous effects in this unit. The melting of the alloy itself is key. Stiffness tests were inconclusive, since soft non-metallic sleeve bearings were used. All tests were run in air at room ambient temperature.

OBSERVATIONS

Foil heaters applied to the wall of the housing bore with RTV worked well, but ones applied to the radius and leading edge of the shaft paddle delaminated. In an attempt to prevent delamination, a top layer of RTV was applied to the foil heaters. They held, but blew-out when powered-up due to the reduction of heat transfer rate. A cartridge heater in the shaft centerline is definitely the way to go. The approach is much cleaner, as there are no heater wire feed-throughs, RTV mess, delamination, or burn-out issues. For best efficiencies of the cartridge heater, intimate contact area must be preserved. Housing heater wires were passed through a hole in the housing adjacent to the fill plug and RTV'ed without incident.

The melting alloy was very easily poured into the warmed mechanism. The unit was assembled and disassembled many times. The only time-consuming task was to scrape off a thin residual film of the alloy from wetted surfaces. No signs of wear or scoring have been noticed on the housing, shaft, sleeve bearings, or o-rings. An automotive type paper gasket was tried at the housing-to-end-fitting interface and performed very well.

LESSONS LEARNED

Given the findings mentioned above, our next test unit will do the following:

- use a cartridge-type shaft heater for simplicity
- use precision ball bearings for increased stiffness
- minimize the amount of alloy used for weight and heat-up time benefits
- start with a clean sheet of paper in design

We made use of a spare housing, and what we thought was convenient became a trap. It put unnecessary constraints and compromises into our test design.

ACKNOWLEDGEMENTS

Those who assisted in generating this patent have encouraged me to spread this new idea to like industries in America and overseas.

REFERENCES

"Rate Controllable Damping Mechanism" U.S. Patent 4,842,106

NEW	OLD	BENEFIT
solid rigid joint	adequately rigid joint	improved stiffness
zero backlash	some backlash	simplified attitude controls
no latch mechanism	latches required	improved torque margin
leaky alloy goes solid	leaky fluid migrates	near zero risk of contamination
low complexity	very complex	ease of assembly
wide tolerances	tight tolerances	ease of machining
a few simple drawings	many precision drawings	simplicity of design
fill on a workbench	fill in a vacuum	air bubbles permitted
bearings are optional	bearings are required	lower cost
assemble on a workbench	clean room assembly	insensitive to contamination
no fluid filtering	highly filtered fluid	tolerant to particulates
no launch locks	launch locks required	low shock
narrow paddle	wide paddle	larger deployment angle
no temperature compensator	compensator required	weight savings
phased deployments	single deployment	more applications
independent of bulk temperatures	bulk temperature sensitive	no thermal analysis
range of deployment rates	unit has one rate	greater versatility
simple "melting ice cube" analysis	complex non-Newtonian fluid	less modeling
heat dependent performance	torque dependent performance	load independence

Table 1. Summary Comparison Chart of New vs. Old

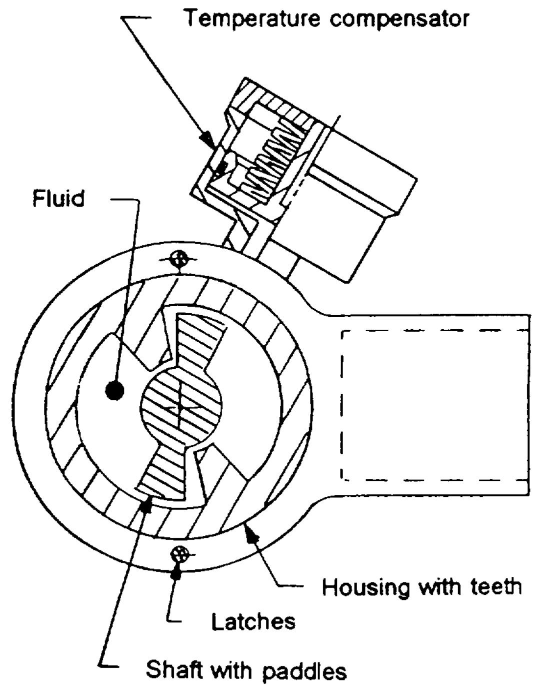

Figure 1. Conventional Fluid Filled Damper
(HS-376 Omni Actuator)

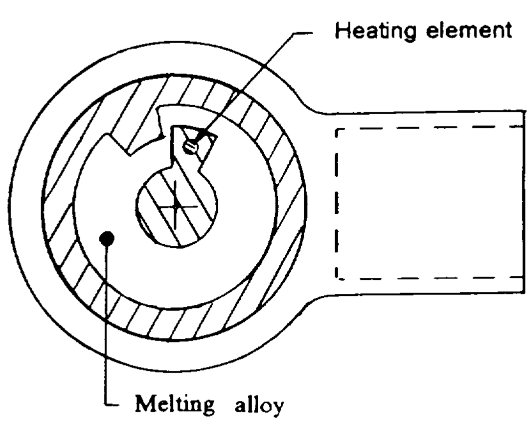

Figure 1A. Low Melting Temperature Alloy Damper

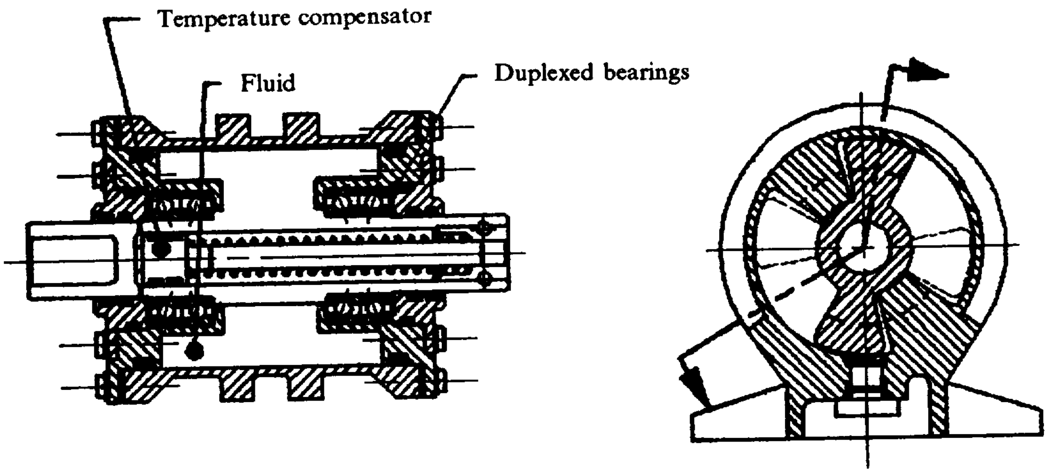

Figure 2. Conventional Fluid Filled Damper
(HS-601 Solar Wing Actuator)

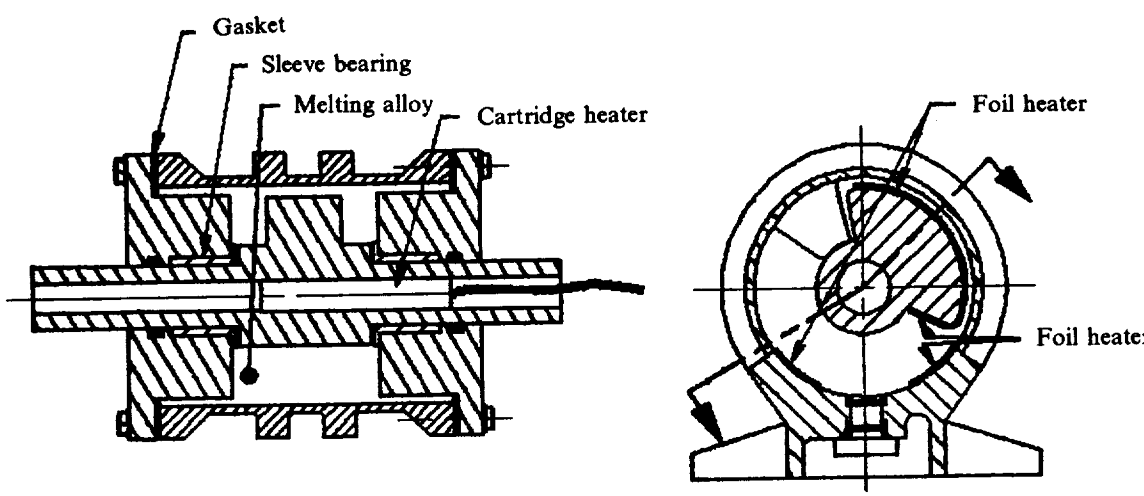

Figure 2A. As-Tested Low Melting Alloy Damper

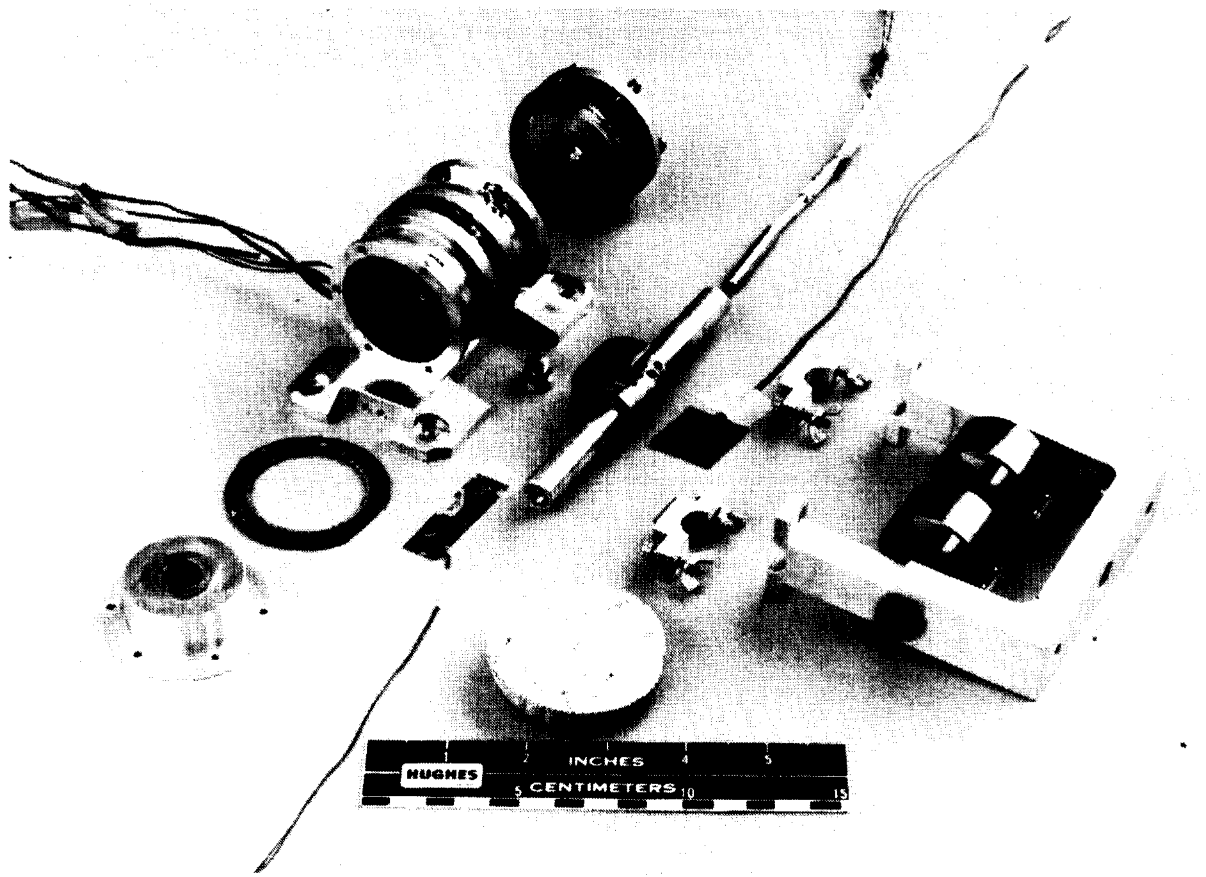

Figure 3. Exploded View Photograph

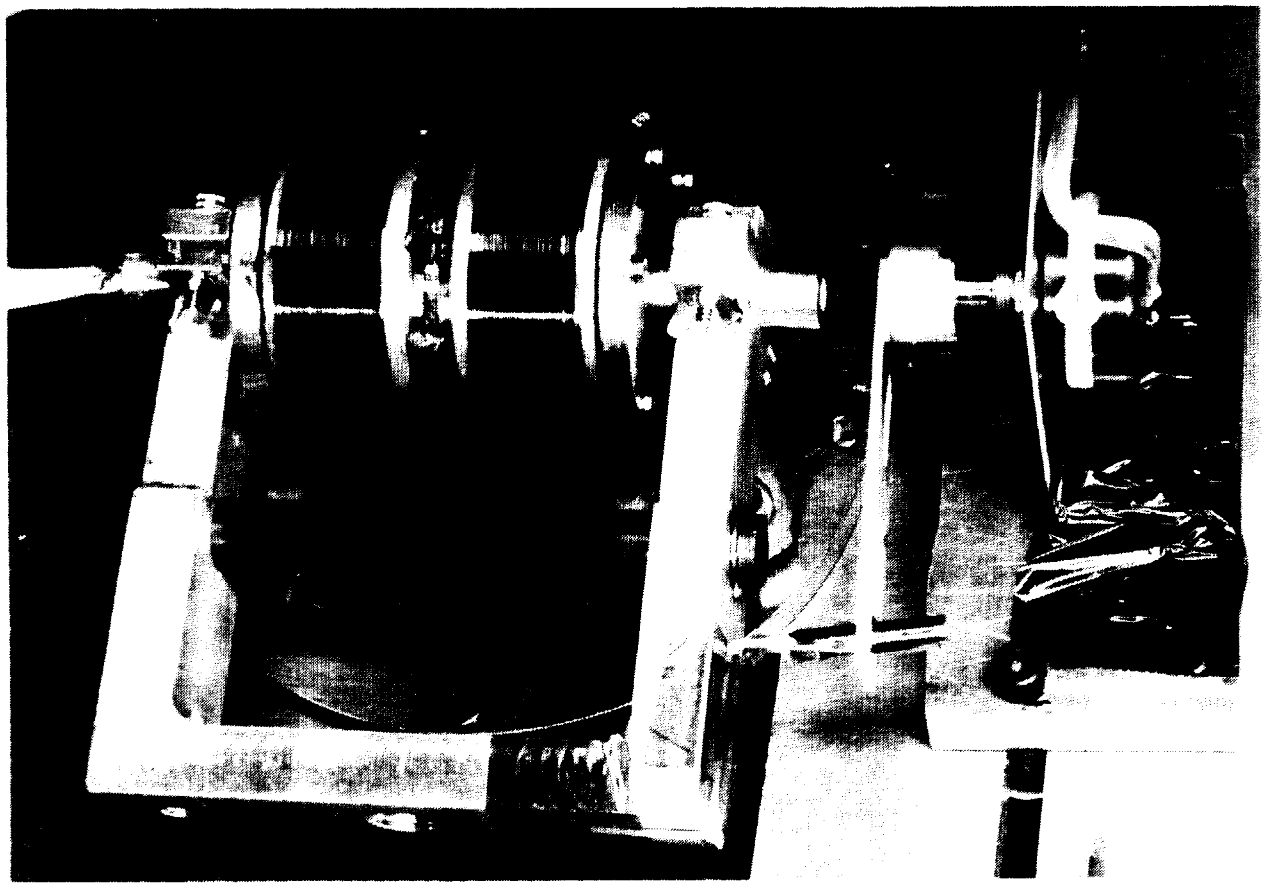

Figure 4. Photograph of Deployment Test Configuration

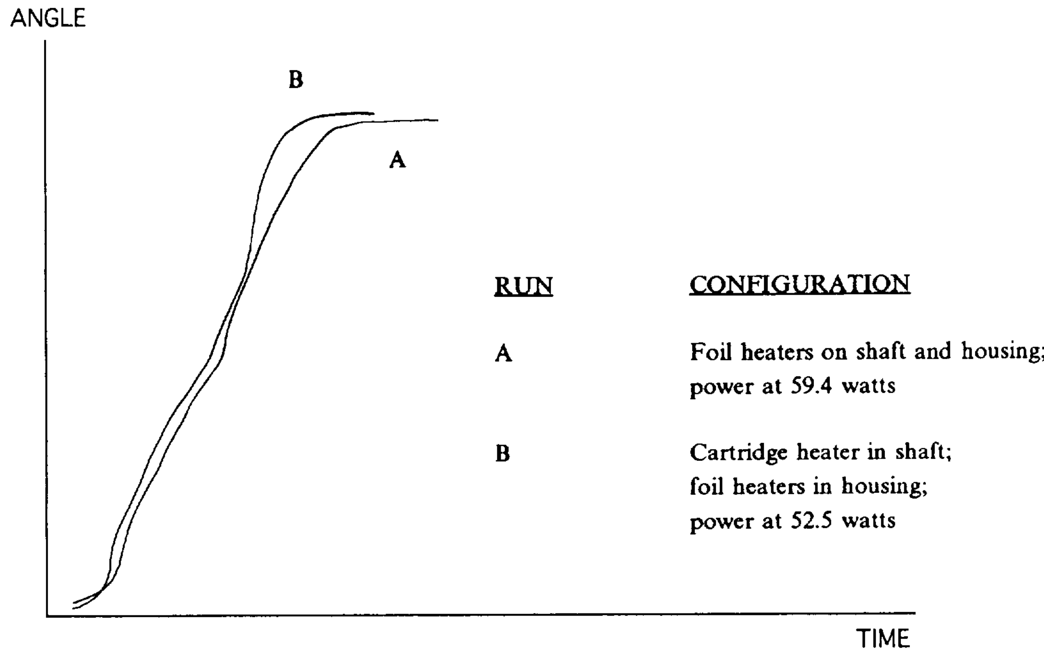

Figure 5. Comparison of Foil Heaters vs. Cartridge Heaters at Similar Power Levels

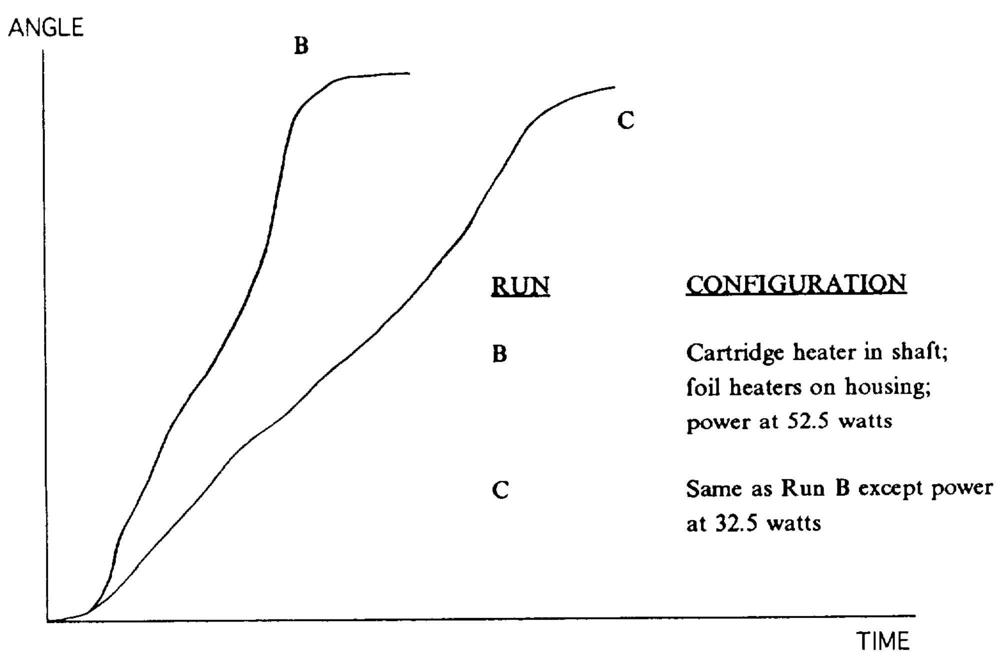

Figure 6. Comparison of Different Power Levels

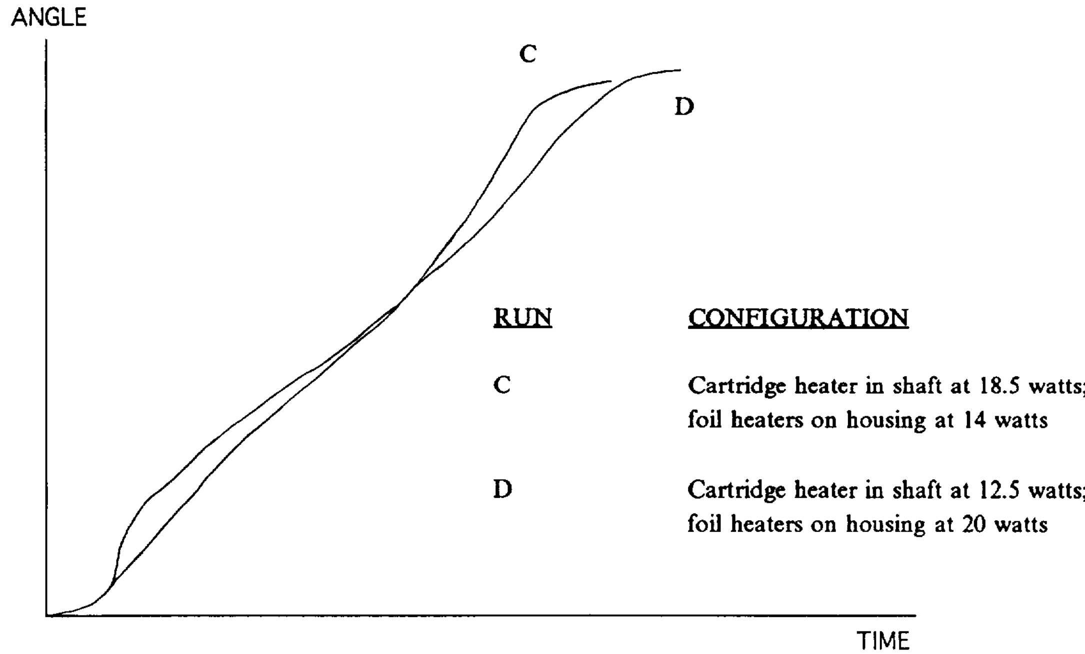

Figure 7. Comparison of Same Power Level, but Different Allocation

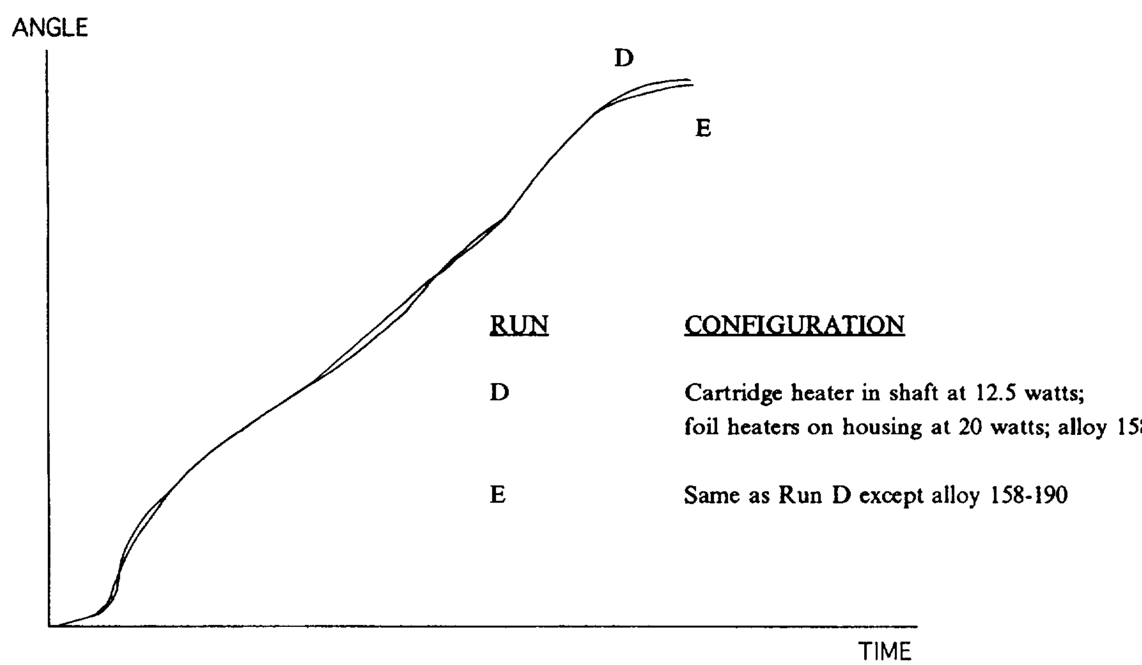

Figure 8. Comparison of Eutectic vs. Non-Eutectic Alloy