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D. N. MATTEO

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EXTENSIBLE STRAIGHT ROD-LIKE STRUCTURE

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Fig. 1

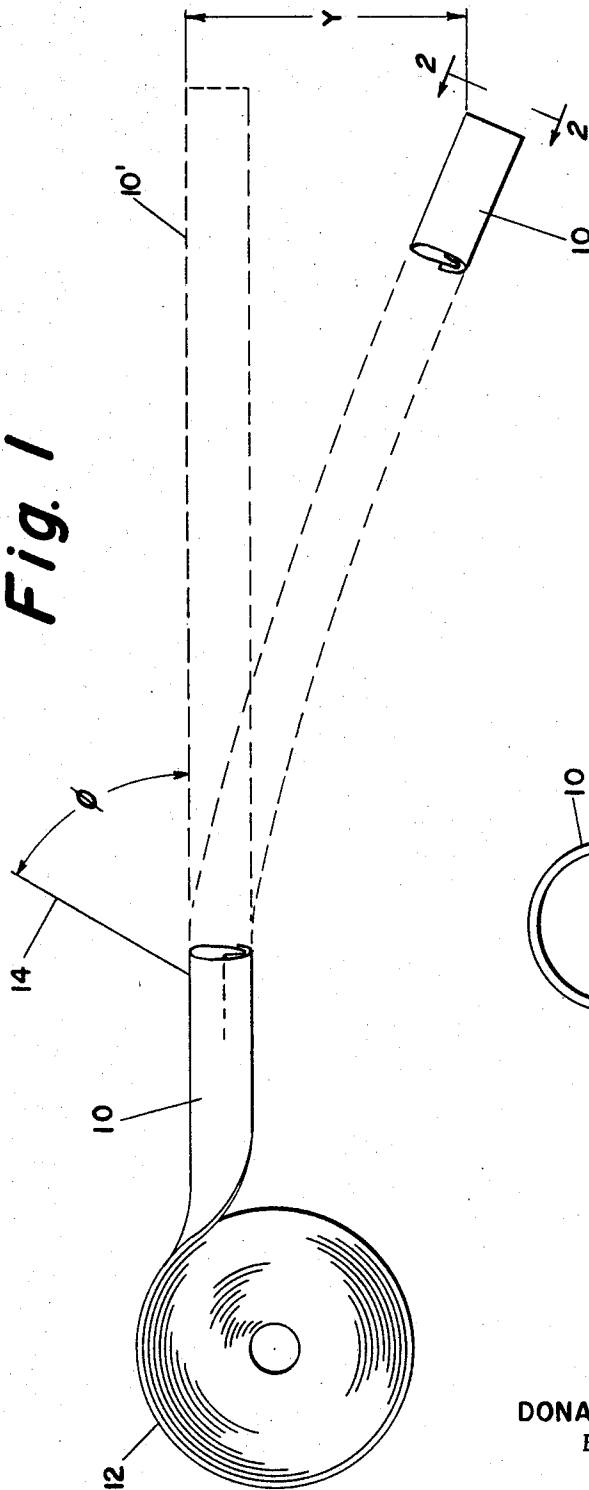
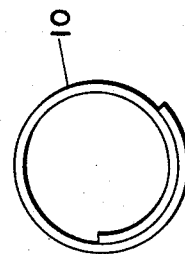


Fig. 2



INVENTOR.
DONALD NICHOLAS MATTEO
BY *Henry W. Kaufmann*
AGENT

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EXTENSIBLE STRAIGHT ROD-LIKE STRUCTURE

Donald Nicholas Matteo, Brookhaven, Pa., assignor to
General Electric Company, a corporation of New York
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This invention pertains to structures for space vehicles, in particular to those which are oriented with respect to the gradient of the local gravitational field.

It is demonstrable analytically that an extended body, such as a long thin rod, placed in orbit around a central body, will tend to turn so that its length is in the direction of the gradient of the local gravitational field. To take practical advantage of this fact, certain experimental space vehicles have been equipped with extensible rod-like structures which are actually elastic strips which, when released from constraints, form long slender tubes which orient the vehicle. This particular collapsible structure is necessary because the gravity gradient around the earth is so small that any rod-like structure (or, for brevity, with the understanding that not only solid rods as such are signified, simply "rods") must be many feet long to be adequately effective. Since it is not feasible in the present state of the art to launch into orbit objects of such dimensions, the elastic strips are given a permanent set which causes them, when free from constraints, to curl around their long axes to form long thin approximately circular hollow right cylinders. For launching, they are forcibly rolled around their short axes and placed under constraints to retain them so while they are carried, stowed in the vehicle, into orbit. After entry into orbit, they are paid out, forming themselves into tubular rods.

It has been the custom of the prior art to employ extensible rods made of beryllium copper alloy of the order of two one-thousandths of an inch thick, and of such width that it forms a cylinder approximately one-half inch in diameter when released from constraints, there being approximately one-half turn overlap where there are two thicknesses of strip lying against one another. Such a structure is mechanically adequate for its purpose, but it has a curious disadvantage. A body in orbit around the earth is exposed to intense radiation from the sun, to radiation of much smaller magnitude from the earth, and to negligible radiation from other parts of space. In consequence, there is a net heat flow through the rod, with resulting thermal gradients, which produce differential expansion of the rod. While this expansion is not great enough to be significant in short lengths of such material, because of the great lengths involved and because the gravity gradient is a highly precise standard of reference, the resulting distortion of the rods when used to orient an orbiting vehicle is objectionable. It has been proposed to reduce the influx of heat by silver-plating the beryllium copper to give it a surface of minimal absorptivity. This is insufficient, partly because the plating tends to flake off when the strip is rolled up prior to launching, but also because it does nothing but reduce the heat flow, and affects the thermal distortion only indirectly. Plating is also subject to removal by bombardment by meteoroids; a homogeneous material is preferable for this reason.

It has occurred to me that a brute force attack upon

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the problem of thermal deflection of gravity-gradient orienting rods by simple attempt to reduce heat influx is necessarily limited in its effects, since no perfectly reflecting substance is known. I have evolved a factor of merit of material which takes account not only of the surface absorptivity but also of the bulk parameters of the material. By the use of this factor of merit, I have selected from a large number of materials of suitable mechanical properties one having such a combination of properties that it is superior to the beryllium copper now conventionally used and also to many other alloys which, in the absence of the criteria I teach, would appear equally good.

Thus the general object of my invention is to provide extensible rods, for orientation of space vehicles, which will during use suffer minimal distortion from thermal gradients.

For the better explanation and understanding of my invention, I have provided figures of drawing in which:

FIG. 1 represents partly in cut-away an extensible rod-like tubular structure substantially completely extended from a storage reel, and represents its distortion as a result of differential heating from solar radiation; and FIG. 2 represents an end or profile view of the tubular structure.

In FIG. 1, an extensible rod-like structure 10 is represented (partly in section) extended from a reel 12, on which it has, by assumption, previously been wound and stored. Radiation 14, represented by an arrow, incident at angle ϕ , strikes and is partly absorbed by structure 10, with resulting non-uniform heating and differential thermal expansion. The dotted line 10' represents structure 10 if the differential expansion did not occur. The displacement of the end of 10 from the end of 10' is shown by γ . FIG. 2 represents an end or profile view of structure 10.

The temperature of the sun is so far above that of the rods extended in space that the thermal flux into the rod from the sun may be regarded simply as proportional to the absorptivity of the surface of the rod. In other words, a constant-flux situation, analogous to constant-current conditions in electricity, exists. Under these circumstances the temperature gradient across the material will be proportional to the thermal resistivity, or inversely proportional to the thermal conductivity, of the material. However, the temperature gradient produces differential expansion only in proportion to the coefficient of linear thermal expansion of the material. The radiation received from the earth is so small compared with that received from the sun that it may be neglected. The particular temperature reached by the rod does not enter directly into the present evaluation of a material because it is the temperature differences in the rods, produced by thermal flux through the piece, which produce differential expansion and consequent distortion which it is my purpose to minimize.

Thus, it appears possible to express a factor of thermal merit for materials for making extensible rods to be used for orientation of satellite bodies by gravity gradient. Such a factor must be proportional to the following:

$$\frac{\text{Thermal conductivity}}{\text{Absorptivity} \times \text{Coefficient of linear thermal expansion}}$$

It would appear a priori that this includes all the factors of interest. This is not so. The basic function of the rod is to provide a straight structure; and, in order to be extensible in the manner indicated, it must be capable of being flattened without being stressed past its yield point. It might appear that the latter requirement is trivial, since by making the strip material sufficiently thin, its section modulus may be reduced arbitrarily. However, this (as will be shown hereinafter) increases the temperature differential across the rod. Analysis is necessary, as follows:

When the collimated energy of the sun strikes the surface of the tubular gravity gradient rods in space, the face of the rod on which the energy is incident will be heated to a higher temperature than that which faces cold black space. This temperature differential can be expressed as:

$$\Delta T = \frac{\alpha S r^2}{k t} \sin \phi$$

where:

ΔT =temperature gradient across rod ($^{\circ}$ F.)

α =solar absorptivity

k =thermal conductivity (B.t.u./hr.-ft.- $^{\circ}$ F.)

r =rod radius (ft.)

t =material thickness (ft.)

S =solar radiation constant=440 B.t.u./hr.-ft. ^{2}

ϕ =angle between sun radiation vector and axial rod centerline

It can be seen from this expression that the worst case occurs when the sun/rod angle is 90° .

Once the thermal gradient (ΔT) is known, the rod end deflection (due to thermal bending) may be described by the equation:

$$\gamma = K_3 1n \sec \frac{X}{K_3}$$

where:

γ =rod tip deflection normal to the undeflected shape (ft.)

X =rod length (ft.)

$$K_3 = \frac{2r}{\mu \Delta T}$$

where:

r =rod radius (ft.)

μ =rod material coef. of thermal expansion (in./in./ $^{\circ}$ F.)

T =temp. gradient ($^{\circ}$ F.)

It can be seen from the above equations that the ways to minimize the ΔT (and thus the bending deflection) are to:

- Decrease rod radius (r)
- Increase rod material thickness (t)
- Increase rod material conductivity (k)
- Decrease rod surface solar absorptivity (α)

However, for a given rod material, the ratio t/r is limited by the allowable flattening stress in the rod. The applied flattening stress (when rolled on the storage drum) is defined as:

$$f = \frac{E t}{2r}$$

where:

f =applied stress (p.s.i.)

E =Young's modulus (p.s.i.)

Therefore, the increase in t and decrease in r (desired to minimize bending deflection) are limited by the modulus of elasticity and the allowable flattening stress of the material. The problem of minimizing the thermal bending deflection, therefore, resolves itself into one of selecting a rod material with:

- A high ratio of allowable stress/ E
- A high thermal conductivity
- A low solar absorptivity.

Accordingly, the thermal sensitivity factor:

$$\frac{\mu \alpha E}{k F_{TY}}$$

where F_{TY} =permissible stress

is a measure of thermal bending sensitivity of candidate rod materials. The material which demonstrates the lowest such factor is the one that is optimum from a thermal bending standpoint. This sensitivity factor is, of course, a reciprocal factor of merit; i.e., it should be a minimum for best results.

The thermal sensitivity factor does not include the density of the material. If the mass per unit length of the rods were a controlling factor in their effectiveness (as would be the case if exclusive reliance were placed upon the rods alone for orientation), the density of the selected material ought to appear in any valid factor of merit. In practice, however, masses may be attached to the distal ends of the rods to remedy any lack of mass in the rods themselves, and thus the density is not a controlling factor. It happens, furthermore, that the material whose use is disclosed herein is of greater density than that of the conventional beryllium copper (0.380 pound per cubic inch versus 0.297 pound per cubic inch), so that any measure of merit which included density would indicate a fortiori the superiority of the more desirable material.

In the investigation of the numerous alloys whose desirability for application in extensible rods may be determined according to my teaching, I have found an alloy, commercially available, which is superior to the conventional beryllium copper in having a thermal sensitivity factor approximately one-sixth that of beryllium copper. This alloy is sold by the Handy and Harmon Corporation of New York, N.Y., under the trade name of Consil 995. I also investigated a commercial alloy of comparable mechanical properties designated as X. In the table hereinafter, I give the weight composition of these alloys, and compare their thermal sensitivity factors with that of beryllium copper. Consil 995 is predominantly silver, and consequently has a highly reflective surface. In terrestrial environment, this silver surface must be protected against sulphur compounds, which may be done readily by plastic coating or other known protective means. When this is done, the absorptivity for solar radiation is about 0.09. This is slightly higher than the figure of 0.07 commonly used for visible radiation only, because much of the solar radiation lies outside the visible region. Hardening of the dead soft material is accomplished by heating in an oxidizing atmosphere to about 1250 degrees Fahrenheit. This compares with precipitation hardening by heating to a somewhat lower temperature, which is used with beryllium copper. It is desirable for the application under consideration that the material used be not markedly strain hardening, as fabrication and deformation are likely to produce uncontrolled hardening.

TABLE

Material	Consil 995	X	Be-Cu (Berylco 25)
Chemical Comp. (Percent by Weight).....	99.5 Ag, .3 Mg, .2 Ni.....	72.0 Ag, 28.0 Cu.....	Be, 1.8-2.05; Cobalt, .18-.30; Cu, Balance.
Mechanical Properties (Pounds per Square Inch):			
Ultimate Stress.....	65,000 to 70,000.....	70,000.....	185,000 to 210,000.
Yield Stress.....	50,000.....	53,000 to 58,000.....	100,000.
Young's Modulus.....	13×10^6	12.6×10^6	19×10^6 .
Unit Weight (lb./in. ³).....	.380.....	.365.....	.297.
Thermal Properties:			
α	.09.....	.214.....	.418.
k, B.t.u./hr.-ft. °F.....	155.....	200.....	75.
μ , (in./in.)/°F.....	10×10^{-6}	10×10^{-6}	9.9×10^{-6} .
Thermal Sensitivity Factor.....	1.51×10^{-6}	2.45×10^{-6}	10.6×10^{-6} .
$\mu \propto E$			
kF TR			

It may be seen that the first alloy listed has a sensitivity factor, or reciprocal factor of merit surprisingly smaller than that of the other materials which a priori would seem to be equally suitable for the purpose.

What is claimed is:

1. The method of orienting a space vehicle in a gravitational field which comprises:
- (a) providing a roll of strip of a material having a thermal sensitivity factor as defined of less than 1.6×10^{-6} attached to said vehicle;
- (b) the said strip being preformed to have a permanent set which causes it to assume, when released from constraints, a shape approximating a circular cylinder with its axis parallel to the length of the strip;
- (c) unrolling a portion of the said strip to extend from the said vehicle, free from constraints, whereby it is

permitted to assume the said shape and to extend in the said gravitational field.

2. The method claimed in claim 1 in which the said material is an alloy having the approximate weight composition:

	Parts
Silver	99.5
Magnesium	.3
Nickel	.2

References Cited

- "Ag-2 Silver Alloy," Alloy Digest, Engineering Alloys Digest, Inc., September 1956.
- CHARLES N. LOVELL, Primary Examiner.
- DAVID L. RECK, Examiner.
- H. F. SAITO, Assistant Examiner.