

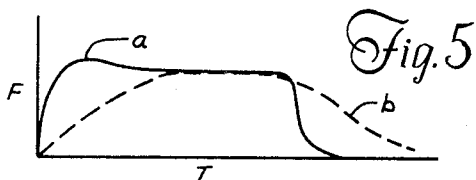
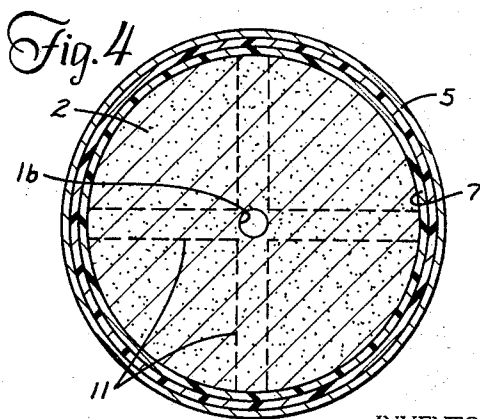
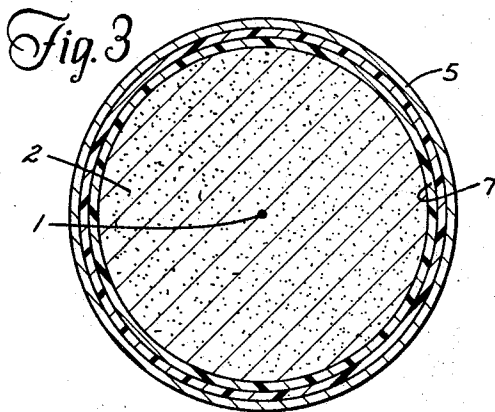
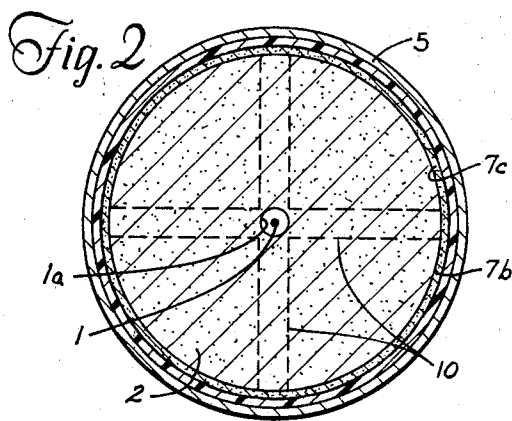
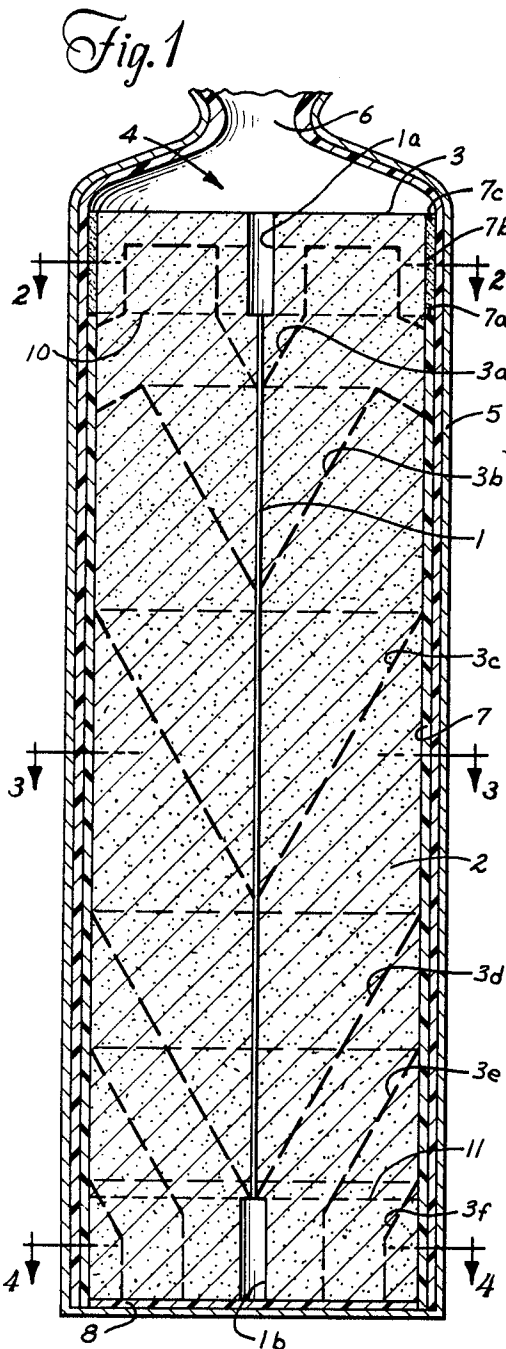
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3,352,244

GAS-GENERATING GRAIN

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3,352,244

GAS-GENERATING GRAIN

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ABSTRACT OF THE DISCLOSURE

A single wire gas-generating grain provided with a recess in both the head and the ignition end, with the wire communicating with these recesses. The sides of the grain are inhibited, except for a portion adjacent to and circumscribing the ignition end and extending a predetermined distance along the sides, in order to provide a total ignition surface area equal to the burning area provided by the single wire grain after the conical burning surface has reached equilibrium. Similarly, the recess in the head end changes the burning characteristics when the apex of the conical burning surface reaches it, such that the burning surface area remains constant until the entire grain is consumed.

This invention relates to a new and improved end-burning gas-generating or propellant grain. Particularly, the invention relates to an end-burning gas-generating or propellant grain containing a single longitudinally-embedded metal heat conductor having improved rapid tail-off and start-up characteristics.

For purposes of this invention the term gas-generating or propellant grain means a shaped charge comprising a matrix composition which is self-oxidant, namely capable of self-sustaining combustion to generate high temperature gases, such as CO, CO₂, H₂, H₂O, etc. Such gases can be used for any suitable and well-known purpose, such as the generation of power or thrust as in driving a turbine or a reaction motor, the testing of high temperature insulation materials, or the production of gases for attitude control, and the like. The gas-generating grain matrix can be any conventional propellant composition. It can be, for example, of the double base type such as nitrocellulose gelatinized with nitroglycerine, or of the composite type, such as a mixture of an organic fuel, e.g. a polymer such as polyvinyl chloride, polysulfide, polybutadiene, etc., and a finely-divided inorganic oxidizer, e.g. ammonium perchlorate or ammonium nitrate. It can include additives such as metal fuel powders, chopped metal wires or staples and burning rate modifiers, and the like.

End-burning grains containing elongated metal heat conductors, such as wires, which are embedded in intimate, gas-sealing contact with the propellant matrix, positioned normal to the initial ignition surface of the grain, and continuously disposed in the direction of flame propagation of the grain, are known to the art. See, for example, U.S. Patent 3,140,663. Such grains, referred to herein as wired grains, have eliminated the disadvantages of prior end-burning grains by greatly increasing burning surface area and, thereby, the effective mass burning rate and mass rate of gas generation to the degree requisite for high performance. The large burning surface area of the wired end-burning grains results from the fact that the matrix burns at an exceedingly rapid rate along the

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metal heat conductor thereby producing recessing of the burning surface, with the wire at the apex of the formed recess. Thus wired end-burning grains can now be employed in place of grains having longitudinal perforations or lateral recesses, expedients which are disadvantageous since they reduce grain strength and motor loading capacity.

Such grains in practice have required the use of a large plurality of laterally-spaced, longitudinally-embedded continuous wires, in some cases as many as 50 or more, in order to obtain rapid attainment of equilibrium burning and, particularly, rapid tail-off with minimum formation of slivers. The reasons for this are explained in the above-referenced U.S. Patent 3,140,663.

The use of a plurality of wires has certain disadvantages. Embedding the many fine wires in correct position and without breaking is a rather slow, difficult, and costly processing step.

However, use of a single wire has posed severe problems of long tail-off because the recessed cone formed along a single wire continues to deepen and widen until it encompasses the entire width of the grain. When burning has progressed along the full length of the single wire, the large remaining forward or head-end portion of the grain surrounding the conical burning surface must then burn out at the normal linear burning rate of the propellant matrix. Not only is the high mass burning rate induced by the metal wire no longer available but the large conically-recessed burning surface results in a continuously regressive burning surface area. The net effect is that the rate of gas generation regresses over a long tail-off period.

The use of a single wire poses still another problem, which has hitherto been minimized by the use of a plurality of wires. The burning surface area increases progressively until the inverted cone formed with the single wire at its apex intersects the periphery of the grain. This delays unduly for many applications the onset of the equilibrium or constant burning surface area. This problem can be eliminated by the pre-coning of the initial ignition surface of the end-burning grain with the wire exposed at the apex of the conical recess, as described in U.S. 3,140,663, or by slotting the ignition surface to increase the initial ignition surface area. Such recessing of the grain, however, reduces the total volume of the grain proportionately to the increase in initial ignition surface area provided. In the case of a single-wire grain, the depth of a conical or slotted recess adequate to provide the equilibrium burning surface area at ignition would also unduly weaken the ignition end of the grain.

The object of the invention is to provide an end-burning grain containing a single, longitudinally-embedded metal heat conductor, which is characterized by rapid tail-off.

Another object is to provide an end-burning grain containing a single, longitudinally-embedded metal heat conductor, which is characterized by rapid attainment of equilibrium burning.

Other objects and advantages will become obvious from the following detailed description and the drawings, in which like parts are identified by the same reference character:

FIGURE 1 is a longitudinal sectional view through a single-wired gas-generating grain according to the invention and the effect on surface area of the grain during burning. The grain is shown seated in the combustion chamber of a gas-generating device.

FIGURES 2, 3 and 4 are cross-sectional views taken respectively along lines 2—2, 3—3, and 4—4 of FIGURE 1.

FIGURE 5 illustrates a comparison in thrust versus time between a conventional single wired grain having un-recessed end surfaces with the wire extending from end to end of the grain and a similar grain modified and improved in accordance with this invention.

We have discovered that the desired rapid tail-off can be obtained in a single-wire grain by terminating the wire at a predetermined distance from the forward or head end of the grain, and longitudinally recessing the head end of the grain to a depth sufficient to expose the forward end of the wire. The head-end recess together with the conical burning surface present when burning has reached the end of the wire continue to provide until burn-out substantially the same large burning surface area induced by the wire, with concomitant rapid tail-off.

We have found that equilibrium burning can be achieved with a single-wire grain with minimum sacrifice of total grain volume by inhibiting with an insulator coating the side or peripheral surface of the grain with the exception of a portion adjacent to the ignition end of the grain. Preferably the ignition end is also provided with a recess extending in the longitudinal direction of the grain with the base of the recess intersecting an exposed ignition end of the wire. The size of the recess is considerably smaller than that required to achieve rapid equilibrium burning in the absence of the peripheral uninhibited portion.

FIGURE 1 illustrates diagrammatically the burning phenomenon which occurs during combustion of an end-burning propellant grain 2 having longitudinally embedded in it normal to the plane of the initial ignition surface 3 a single metal wire heat conductor 1. For illustrative purposes, the propellant grain is shown in the combustion chamber 4 of gas-generator 5, equipped with restricted nozzle 6. The end-burning grain is inhibited on its lateral surfaces by inhibitor coating 7 which essentially begins at 7a and extends continuously to the forward or head end of the grain which is also restricted against burning by an inhibitor coating or by plastic cement bonding 8. The aft portion 7b of the lateral surface of the grain is free of inhibitor coating. The space between the uninhibited grain surface 7b and the wall of the combustion chamber 4 may be filled with a readily disintegrable support material 7c, preferably resilient, e.g., polyurethane foam. The grain is recessed at the aft, or ignition, end by opening 1a which extends to the aft, or ignition, end of the metal heat conductor 1. The grain is recessed at its forward end by opening 1b which extends from the forward end of metal heat conductor 1 to the forward end of the grain 2.

FIGURE 1 shows the progression of the burning surface during the combustion cycle from the initial ignition surface 3. At 3a burning has progressed from uninhibited grain surface 7b, aft end 3, and surface of recess 1a. The burning surface moves rapidly along the longitudinally-embedded wire with the formation of inverted conical burning surface 3b progressing to the conical burning surface 3c that has widened to intersect the periphery of the grain. At 3d, the grain has burned to the forward end of the wire and the grain begins to burn along the wall of opening 1b. At 3e and 3f, the remaining portion of the grain is being rapidly consumed as the conical burning surface and the burning surface provided by recess 1b continue to burn with a large, substantially constant, combined surface area substantially to burn-out.

In this illustration, the combined surface area exposed for burning from the time of ignition to time of complete combustion remains substantially constant, thus providing high initial, nearly equilibrium gas-generation rate shortly after ignition and maintaining the substantially same rate throughout nearly the entire period of burning.

FIGURE 5 illustrates the advantageous thrust performance (F) of a propellant grain of the invention (line a) in comparison with a conventional single wired grain (line

b) of like propellant composition. In FIGURE 5, line a shows the rapid attainment of equilibrium thrust (F) with time (T) and a sharp tail-off. Line b shows the gradual rise of thrust to equilibrium and gradual tail-off.

The superior performance of the propellant of the invention is thus clearly shown.

The metal heat conductor is preferably a wire, which can be of any suitable cross-sectional shape, e.g., circular, rectangular, oval, or the like. It can also be a flat, narrow strip which as employed herein can be considered a flat wire. The maximum thickness of the conductor in at least one transverse direction should be about 0.05 inch, preferably a maximum of about 0.02 inch. Optimum thickness is generally about 0.003 to 0.01 inch.

The metal heat conductor is preferably silver, copper, or aluminum, although it can be any other metal or metal alloy having good heat conductive properties, such as platinum, tungsten, magnesium, molybdenum, steel, and the like.

The metal heat conductor can comprise a core of one metal species, such as silver, coated with a different metal species, such as a metal of higher melting point, e.g. tungsten.

The metal heat conductor can be coated with an inert insulator type coating to tailor the mass burning rate to a level between that of the propellant matrix and the burning rate induced by a bare metal conductor of the same metal species and size. Such coatings and their effect are described in U.S. 3,109,374.

The metal heat conductors can also be coated with self-oxidant coatings of lower or higher linear burning rates than that of the propellant grain matrix to reduce or increase the mass burning rate produced by the bare metal conductor of the same metal species and size. Such coatings and their effect are described in U.S. 3,109,375.

As aforementioned, the grain matrix can be any conventional solid self-oxidant, gas-generating composition. It can also be a plastic semi-solid. Cohesive, shape-retentive monopropellant compositions, which are characterized as plastic or semi-solid because they flow at ambient or normal temperatures under moderate stress or pressure, can be loaded into the combustion chamber of a gas-generating device or rocket motor, where they function as end-burning grains. Examples of semi-solid monopropellant compositions suitable for such use are disclosed in U.S. 3,095,334, 3,107,187, 3,113,894, and 3,196,059.

When the matrix of the grain tends to plastic-flow, the ignition end and forward end recesses can be filled with plugs of a readily disintegrable material, preferably a rigid cellular material, such as foamed glass, foamed polystyrene, foamed polyurethane, or the like.

The equilibrium burning surface area and mass burning rates for a particular grain are determined by such factors as the linear burning rate of the grain matrix composition, the metal species of the heat conductor, its cross-sectional dimensions, and the coating on the conductor, if any. When the above factors have been determined, the total surface area exposed on the aft peripheral portion 7b of the grain, and the required shape and surface area of recess 1a can be readily determined to give an initial burning area substantially equal to the equilibrium burning surface area which will be obtained when the cone burning surface has reached its equilibrium size as shown at 3c. As a result equilibrium gas-generation rate is rapidly attained.

The recess at the aft ignition end of the grain need be only large enough in diameter to permit quick ignition of the propellant matrix 2 on its inner wall. The advantageous depth or length of the recess 1a can be determined by routine calculation or experimentation. The optimum length will be such that the cone formed by the burning of the propellant grain 2 along the embedded metal heat conductor 1 will have reached equilibrium size by the time that the uninhibited lateral or peripheral portion of the grain has been consumed. It will be understood that the

depth of the recess and the surface area of the lateral un-

inhibited portion of the propellant grain makes possible a wide range of initial start-up rates.

The cross-sectional shape of the perforation 1a is not critical. For example, it can be circular as illustrated by the solid lines, star-shaped, or cruciform, as illustrated by the dotted lines 10 in FIGURES 1 and 2. A circular cross-section is preferred in order to retain a maximum volume of propellant matrix.

The recess 1b, at the forward end of the grain, should be large enough to permit the propellant matrix to be completely consumed at substantially equilibrium rate after the grain has burned past the forward end of the metal heat conductor. The cross-section of the recess can be circular as illustrated by the solid lines, star-shaped, cruciform, as illustrated by the dotted lines 11 in FIGURES 1 and 4, or any of the known designs. Preferably, the recess is made in the form of slots running from side to side of the grain and intersecting the metal conductor at the longitudinal axis of the grain. The recess, regardless of its cross-sectional shape, extends from the forward head-end surface of the grain and intersects the forward end of the metal heat conductor.

In some cases, it may be desirable to insert into the forward recess a plug of a material which melts or otherwise disintegrates rapidly upon contact with the combustion gases in order to increase the structural strength of the forward end of the grain. Preferably the material is a cellular material such as foamed glass, foamed polystyrene, foamed polyurethane, or the like.

The inhibitor coating 7 on the propellant grain 2 can be any type of insulator coating conventionally used to restrict burning of the coated surface. The length of uninhibited grain surface 7b, measured from the end surface 3 of the grain usually will be minor compared to the length of the inhibited portion of the grain and will depend on the total uninhibited surface area determined necessary to achieve the object of the invention.

Although this invention has been described with reference to an illustrative embodiment thereof, it will be apparent to those skilled in the art that the principles of the invention can be embodied in other forms within the scope of the claims.

We claim:

1. An end-burning grain having an initial ignition surface and a restricted head-end surface at its opposite end and comprising a self-oxidant, gas-generating matrix having a longitudinal recess extending inwardly from its head end, said grain containing a single elongated metal heat conductor longitudinally embedded in the matrix of said grain and communicating with said recess.

2. An end-burning grain having an initial ignition surface and a restricted head-end surface at its opposite end and comprising a self-oxidant, gas-generating matrix having a longitudinal recess extending inwardly from its head end, said recess comprising a plurality of arms extending radially from the longitudinal axis of said grain, said grain containing a single elongated metal heat conductor embedded in the matrix of said grain along the longitudinal axis thereof and communicating with the intersection of said arms.

3. An end-burning grain having an initial ignition surface and a restricted head-end surface at its opposite end and comprising a self-oxidant, gas-generating matrix, said grain being designed to burn progressively from one end which is an uninhibited ignition end, said matrix containing embedded therein along the longitudinal axis thereof a single elongated metal heat conductor which is continuously disposed in the direction of flame propagation of the grain, said grain having an axially oriented, longitudinal recess extending inwardly from the head end thereof and communicating with said metal heat conductor.

4. A grain as defined in claim 3 wherein said longitudinal recess comprises a plurality of arms extending radially from the longitudinal axis of said grain.

5. An end-burning grain comprising a self-oxidant, gas-

generating matrix, said grain having an inhibitor coating on the side surfaces thereof except for a portion adjacent to and circumscribing the ignition end of said matrix and extending a predetermined distance along said side surfaces, and a longitudinal recess extending inwardly from said ignition end, said grain containing a single elongated metal heat conductor embedded in the matrix of said grain along the longitudinal axis thereof and communicating with said recess.

6. A grain as defined in claim 5 wherein said longitudinal recess comprises a plurality of arms extending radially from the longitudinal axis of said grain.

7. An end-burning grain comprising a self-oxidant, gas-generating matrix, said grain being designed to burn progressively from one end which is an uninhibited ignition end, said matrix containing longitudinally embedded therein a single elongated metal heat conductor which is continuously disposed in the direction of flame propagation of the grain, said grain having a longitudinal recess extending inwardly from said ignition end and communicating with said metal heat conductor, and an inhibitor coating on the side surfaces thereof except for a portion adjacent to and circumscribing said ignition end for a distance along said sides sufficient to provide a burning surface area which, when combined with the uninhibited ignition end surface area and the burning surface area provided by the perforation provides a gas generation rate approximating that attained by the recessed conical burning surface formed as the grain burns along the metal heat conductor when said conical burning surface reaches equilibrium burning conditions.

8. An end-burning grain having an initial ignition surface and a restricted head-end surface at its opposite end and comprising a self-oxidant gas-generating matrix having at each end an inwardly extending longitudinal recess and a single elongated heat conductor longitudinally embedded in the matrix of said grain and being disposed between and communicating with the inner ends of said recesses.

9. A gas generating grain as defined in claim 8 wherein one of said longitudinal recesses comprises a plurality of arms extending radially from the longitudinal axis of said grain.

10. An end-burning grain having an initial ignition surface and a restricted head-end surface at its opposite end and comprising a self-oxidant, gas-generating matrix having

(a) an inhibitor coating on the peripheral surface thereof except for a portion extending inwardly from one end thereof, said one end being the ignition end,

(b) a first longitudinal recess extending inwardly from said ignition end,

(c) a second longitudinal recess extending inwardly from the head end, and

(d) a single elongated heat conductor embedded in the matrix of said grain along the longitudinal axis thereof and bridging said first and second recesses.

11. An end-burning grain having an initial ignition surface and a restricted head-end surface at its opposite end and comprising a self-oxidant, gas-generating matrix, said grain being designed to burn progressively from one end which is an uninhibited ignition end, said matrix containing longitudinally embedded therein a single elongated metal heat conductor which is continuously disposed in the direction of flame propagation of the grain, said grain having at each end an inwardly extending longitudinal recess along the longitudinal axis of said grain, said metal heat conductor being disposed between the inner ends of said recesses, the peripheral surface of said grain having an inhibitor coating thereon except for a portion extending inwardly from said ignition end for a distance sufficient to provide a burning surface area which, when combined with the uninhibited ignition end surface area and the burning surface area provided by the recess at the ignition end, provides a gas generation rate substantially

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equivalent to that attained by the inhibited portion of the propellant grain as the latter burns along the metal heat conductor at equilibrium burning conditions.

12. A grain as defined in claim 11 wherein the longitudinal recess extending inwardly from the ignition end comprises a plurality of arms extending radially from the longitudinal axis of said grain.

13. A grain as defined in claim 11 wherein the longitudinal recess extending inwardly from the head end of

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said grain comprises a plurality of arms extending radially from the longitudinal axis of said grain.

References Cited

UNITED STATES PATENTS

3,140,663 7/1964 Rumbel et al. 102—98

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