This invention relates to an article of manufacture for the generation of a gas at high pressure. More particularly the invention concerns a solid propellant grain which is restricted with respect to burning surface whereby the gas pressure generated during ignition and initial burning of the grain is controlled.

The gas produced in the combination of grains made from propellants such as flammable base powders (mixtures of nitrocellulose and nitroglycerine) ammonium perchlorate or ammonium nitrate may be used for the propulsion of rockets, the assisted-take-off of airplanes and for the operation of motor starters. Normally only a part of the surface of the propellant grain is permitted to be a burning surface. In order to obtain an "equilibrium" pressure in the combustion chamber a restrictor coating is placed on a predetermined portion (S) of the surface of the propellant grain which restrictor coating remains affixed to some part of the surface of the grain over essentially the entire burning time of the grain. The restrictor coating is relatively non-flammable as compared to the flammability of the propellant portion of the grain. By a combination of surface restrictor coating and grain configuration a particular propellant composition can be burned to provide gas in a given chamber at a predetermined pressure i.e. following the ignition period, until the propellant grain is essentially completely burned. Many materials have been used for restrictor coating such as cellulose acetate, polyvinyl acetate, polyvinyl chloride, asphalt, asbestos, etc.

In the ignition of solid propellant charge under conditions usually encountered in rocket, assist-take-off and gas generator service in general, it is necessary to generate and transfer heat energy to the propellant grain surface until the ignition temperature is reached and combustion of the propellant charge is sustained. This heat energy is provided by an igniter which may consist of any form of combustion exposer powders such as black powder or cannon powder.

Igniters function by releasing a quantity of high temperature gases and hot particles which flow over and give up part of their energy to the propellant grain. The ignitor is designed itself shorty after ignition of the propellant grain becomes self sustaining. During the ignition phase of the combustion of the propellant grain the pressure level in the gas generator chamber, which encompasses the igniter and propellant grain, is determined jointly by the rate of gas generation from the igniter, the rate of combustion of the gas-producing propellant grain, and the size of nozzle orifice for escape of gas from the chamber. Upon the establishment of ignition of the gas-forming propellant grain and the dissipation of igniter gases, an "equilibrium" gas pressure is obtained which is determined by the nature and burning characteristics of the propellant material of the grain, the burning surface area of the grain and the throat area of the nozzle orifice.

For a given propellant charge in the form of a gas-forming grain and associated chamber and nozzle, a specific minimum igniter loading is required to obtain self sustaining combustion of the solid propellant grain and thereby attain a flow of gas at "equilibrium" pressure. The minimum loading varies with the temperature of the grain at the time of firing, being larger for lower temperatures than for high temperatures. It is not practicable to use variable amounts of igniter loading to meet the ignition requirements of extremely low or extremely high temperatures. Thus over ignition may result when igniters suitable for low temperature firing the same grains at high temperature conditions; as a result ignition pressure peaks may occur in the pressure-time trace of the firing of the grain.

The starting of turbojet engines is a difficult feat because of the tremendous mass of metal composing the larger turbojet engines. One of the techniques now used for the starting of such engines involves the use of a solid propellant driven turbine operated starter. The starter is affixed to the frame of the engine and the turbine of the starter is connected by clutch to the rotor of the turbojet engine. A solid propellant grain mounted in a combustion chamber of the starter produces gas which spins the turbine of the starter and turns over the rotor of the turbojet engine to the necessary minimum rotational speed prior to introduction of the fuel to the main combustors. One of the serious problems associated with the use of such starters lies in the torque produced immediately after the igniter loading has been actuated in the starter. This momentary torque results in excessively high maintenance on the bearings and other moving parts of the starter.

An object of the invention is a solid propellant igniter grain which is a sustained burning of which is accomplished by the use of a gas-producing igniter without producing an initial pressure during the burn-out period of the igniter loading and the establishment of sustained burning of the solid propellant which is greater than the "equilibrium" pressure maintained in said combustion chamber during the burning of the solid propellant grain. Another object of this invention is a solid propellant grain which attains relatively slowly the "equilibrium" pressure producable by the solid propellant grain. Still another object of the invention is a solid propellant grain wherein the initial pressure is relatively lower than the "equilibrium" pressure produced by the burning of the solid propellant grain. A particular object of the invention is a gas-generating device utilizing a solid propellant grain and a gas-producing igniter which device does not sustain an initial pressure upon the firing of said igniter which is higher than the "equilibrium" pressure of the burning of the solid propellant grain. Other objects will become apparent in the course of the description of the invention.

Figure 1 is a longitudinal view of an assist-take-off unit with solid propellant grain.

Figure 2 is a cross-sectional view of said assist-take-off unit taken along 2—2.

Figure 3 is an elevation view of a cylindrical gas-producing grain showing short-term restriction of the grain.

Figure 4 is a cross-sectional view of Figure 3.

Figure 5 is a segmentation of Figure 3 with short-term restrictor shown in detail.

Figure 6 is a pressure-time trace illustrating the firing and burning of a gas-propellant grain without short-term restrictor.

Figure 7 is a pressure-time trace of the firing and burning of a grain with one short-term restrictor.

Figure 8 is a pressure-time trace of the firing and burning of a grain with another short-term restrictor.

My improved propellant grain comprises (1) a shaped body portion provided with short-term restrictor coating
applied to a part of said body portion which coating is adapted to restrain burning of the body material beneath said coating for a period of time at least substantially equal to the burn-out time of an igniter adapted to establish the sustained burning of said body portion and not more than about 2 seconds in excess of said burn-out time.

The burn-out time of the igniter is defined herein as the time interval between the actuation of the element which activates the burning of the igniter loading and completion of the burning of said igniter loading. In general burn-out times will range from about 20 mls to as much as 1 second. A mil is defined herein as one-thousandth of a second.

The period of time that the short-term restrictor coating remains on the surface of the body portion of the grain, designated as the residence time, corresponds to a period at least substantially equal to the burn-out time of the igniter and an added period up to about 2 seconds following said burn-out time. The residence time of the short-term restrictor coating depends on several factors. Some of these factors are combustibility, heat conductivity and thickness of the coating as affecting the rate of heat transfer through the coating material. Other factors are ignitability of the body material beneath the short-term restrictor coating as well as the temperature of the grain at the time of firing. The material is preferably the temperature conditions existent in the combustion chamber, that is, the motor, during the burn-out time of the igniter.

Materials which may be used for short-term restriction are adhesive tapes consisting of paper, cloth or plastic provided with adhesive to insure intimate contacting of the tape with the body portion. Thin coatings of asphalt and coatings of liquid self-setting plastics may be applied in the form of solutions thereof or a solution of polyisobutylenes may be applied as a short-term restrictor coating.

The area subjected to short-term restriction determines the effective remaining burning surface of the grain during the ignition period thereof and hence controls the extent of reduced pressure over this period by reducing the mass of gas produced during the ignition period. I have found that a cylindrical ammonium nitrate based propellant grain having a diameter of about 4", and an internal cylindrical aperture of about 1 ½" is restricted effectively over the burn-out period of the igniter charge when fired at about 70° F. by using pressure sensitive plastic tape restrictor having a width of about 5/8" and a thickness of about 0.006". The duration of the short-term restriction time was about 1 second.

The short-term restrictor coatings of this invention are particularly adaptable to ammonium nitrate based gas-forming propellant grains. These grains usually contain about 70% ammonium nitrate, from about 10% to about 25% binder material and from 1% to about 10% combustion catalyst. The binder material is thermoplastic and consists of about 18% to about 50% of a plasticizable synthetic polymeric material, that is, a thermoplastic synthetic resin and from about 50% to about 85% of at least one plasticizer of the synthetic resin. Examples of synthetic resins which may be used are cellulose acetate, cellulose acetate butyrate, polyvinyl acetate and polyvinyl chloride. The plasticizers are oxidizable and preferably oxygen-containing and may be classified broadly as polymeric esters, esters of polyhydric alcohols, ethers of nitrophenols, nitromonocyclic aromatics, esters of polycarboxylic acids, alkyl ethers of polyglycols and polyglycals. Specific examples of plasticizers for the synthetic resins are ethylene glycol diglycolate, the acetins (mono, di and tri), triethylene glycol, di-2-ethylbutyrate, triethylene glycol di-2-ethylhexoate, polyethylene glycol di-2-ethylhexoate, triethyl citrate, acetyl triethyl citrate, dimethyl phthalate, diethyl phthalate, nitromethylpentanediol diacetate, dinitrophenyl propyl ether, dinitrophenyl allyl ether, nitrodiphenyl ethers, dinitrophenoxyethanol, bis(dinitrophenoxyl) ethane, dinitrotoluene, triethylene glycol, and polyethylene glycol. Combustion catalysts which may be used in the ammonium nitrate based grains are the Prussian blues (soluble and insoluble), cerium chlorides, or ammonium chloroformate or ammonium chloroformate or ammonium dichromate or organic combustion catalysts such as the mono sodium salt of barbituric acid, which is particularly suitable as catalyst for grains used in gas turbine starting service. Other components such as asphalt and casings may be added to the ammonium nitrate based grain to improve cold temperature ignition of the grain. Amines may be added to chemically stabilize the grain against decomposition in hot storage. The ammonium nitrate based gas-producing propellant compound may be molded or extruded into grains. The molds may be provided with recesses to provide longitudinal apertures in the grains. These may be cruciform, circular, star-shaped or any other desirable shape in cross section to provide for internal burning of the grain.

An illustrative double base gas-forming propellant which grain may be made of relatively low heat conductivity and short-term restrictors comprises, on a weight basis, about 80% to 85% of a mixture of nitrocellulose and nitroglycerine, about 10% to 15% of a mixture of tricetin and dioctyl phthalate, about 3% of lead soap combustion rate modifier and about 1 to 2% of an amine such as 2-nitrodiphenylamine. Likewise the short-term restrictor coating may be applied to ammonium perchlorate based grains for use in assist-take-off service and for rocket propulsion. A representative composition of such body material comprises on a weight basis about 70% to 75% ammonium perchlorate, about 25% of a binder material consisting of a polyester resin—stylene co-polymer and less than 0.5% of copper chromate inhibitor.

Figure 3 is an illustration of a cylindrical gas-producing grain having body portion 41 which has centrally located longitudinal cylindrical aperture 42 extending therethrough. The annular ends of body portion 41, are restricted with restrictors 43 and 44. The permanent restrictors may consist of plates of synthetic resin such as cellulose acetate or plasticized synthetic resins, asphalt or asbestos tape. These are relatively non-flammable and are of relatively low heat conductivity and hence remain on the annular ends until the grain is substantially completely burned. Thus end-burning below the permanent restrictors is delayed until internal burning surfaces are provided from within said body portion 41. The term “permanent restrictor coatings” and “permanent restrictors” as used hereinafter refer to coatings and restrictors which remain on the surface of the grain until the grain is substantially completely burned.

Body portion 41 is also provided with short-term restrictor coating 45 which may be applied as a pressure sensitive tape which suitably may be of about 0.006 inch thickness. Short-term restrictor 45 encircles the exterior cylindrical surface of body portion 41 and adheres thereto adjacent permanent restrictor coating 44 for a predetermined period, such as 2 seconds, following the ignition of the igniter charge thereby delaying ignition and combustion of the part of the cylindrical surface beneath tape coating 45 over that period when gases from the ignited igniter are effective in producing over-pressure and over the period required to establish sustained burning of the body material.

Figure 4 is a cross section of the grain of Figure 3 showing internal aperture 42, permanent restrictor coatings 43 and 44 and short-term restrictor 45 and Figure 5 is a segmentation of the grain of Figure 3 showing permanent restrictor coating 44 and short-term restrictor coating 45.

In Figure 1, the body of an ATO unit is made up of a tubular member 11 which is closed at one end and which
is provided with threads at the open end. Member 11 is provided with two loops, 12 and 13. These loops are used to hang the unit from a carrier, not shown, which is attached to the wing of the aircraft. This carrier makes it possible to jetison the unit after take-off. A funnel shaped member 14 is provided with a gathering of the threads at the large open end of member 14 with the threads of member 11. Member 14 is provided with a nozzle 16 through which the decomposition products pass. The size of nozzle 16 is determined so as to maintain the pressure inside the chamber formed by members 11 and 14.

Solid propellant fills the cylindrical portion of member 11. The solid propellant of this illustration consists of seven tubular grains, 17, 18, 19, 20, 21, 22 and 23, each having an O.D. of about 3 inches and having a centrally located cylindrical opening 1 inch in diameter the full length of the grains which are approximately 30 inches long. The grains consist essentially of combustion catalyst, oxidizable binder and ammonium nitrate.

Each grain has the annular end areas 24, 25, 26, 24a, 25a and 26a restricted against burning with permanent restraining coating consisting of asphalt or other suitable material such as cellulose acetate in order to limit burning to the cylindrical surfaces. Each grain is restricted with combustible tape 27, 28, and 29 applied to the external cylindrical surfaces near the ends of the grains to prevent excessive escape of the initiators and the firing end of the chamber. The thickness of this tape restrictor may be varied to obtain the desired time of short-term restriction and the width of the tape restrictor may be varied to obtain the desired amount of pressure reduction over the period of ignition and to establish sustained burning of the grain.

Although a multiplicity of separate tubular grains encased in the single combustion chamber are illustrated herein, the invention is not limited to such shaped grains or to use of multiple grains in the combustion chamber. Any particular shape may be utilized. Examples of other shapes are cylinder, cruciform, triform, hexoform, octaform and slab. Where perforated grains are employed the longitudinal perforation may be circular or star-shaped with various numbers of points in the star. Furthermore, a single cylindrical grain having a single longitudinal perforation or multiple longitudinal perforations may be used in the combustion chamber.

The grains are held in position and prevented from sliding back and forth in the chamber by means of a wire grid 30. Wire grid 30 consists of a ring cut to fit the thickness of member 14 and is provided with a grid of metal wires which resist the high temperature existing in the combustion chamber.

An igniter means is positioned within member 14 so as to close off the nozzle 16. The igniter means consists of a contact made with black powder or cannon powder or cannon powder or other easily ignited material, which upon ignition and burning produces a large volume of gas at elevated pressure. Mixtures of the different grades of black powder may be used to adjust the overall burning rate of the powder. The igniter for commercial size assist-take-off grains may consist of the C grade cannon powder granules or mixture of the C grade with black powder having an average diameter less than the C grade. The amount of igniter is determined by the surface area to be ignited, free-volume space in the combustion chamber, the ease of igniting as determined by the surface and composition of the grain and temperature of the grain when fired. A squib 32 for igniting the powder, is attached to the container 31 in communication with the powdered contained therein. Electrical wires 33 connect a wire in the squib to the electrical system of the aircraft and a switch therein.

On one side of the conical portion of member 14 a safety venting means 34 is provided for the combustion chamber. Venting means 34 comprises a tubular member fastened to member 14, which tubular member has full access to the combustion chamber and is provided with a rupture disc, not shown. The rupture disc is of such construction that excess pressure in the combustion chamber will blow out the disc whereby damage to the unit resulting from over-pressure in the combustion chamber is prevented.

The assist-take-off unit is assembled as follows: Grains are inserted into member 11. Venting means 34 is attached to member 14. Igniter 31 is inserted through the large open end and fitted so as to close the nozzle, wires 33 having first been passed through nozzle 16. Wire grid 30 is screwed into the large thrust end of member 14 and the assembled nozzle portion is then screwed onto member 11. The assembled unit is then attached to the wing of the aircraft by loops 12 and 13 and wires 33 are connected to the electrical operating assembly in the aircraft. When the pilot desires to obtain the assist-take-off, he throws the switch which causes a current in wire 33 and heats the firing wire in squib 32 which in turn ignites the powder in container 31.

Container 31 is of sufficient strength to withstand the initial pressure generated by the gases from the powder. However, the hot igniter gas raises the pressure and causes the pressure to rise to a point which cannot be resisted by container 31. Container 31 disintegrates and the fragments are discharged through nozzle 16.

As the gases pass out of the nozzle the reaction acts on the aircraft and adds to the thrust to assist the aircraft propellers and a marked increase in forward speed results. A shorter space of time for take-off and/or a heavier load can become airborne than when propellers only are used.

Tests
A series of ammonium nitrate based turbojet auxiliary turbine starter grains were prepared. These grains were in the form of cylinders approximately 4 inches in length and 5 inches O.D. and were provided with centrally located longitudinal cylindrical apertures having a diameter of 1.5 inches. Both annular ends of the grains were restricted with permanent restrictor disc plates about 4 mm in thickness. These disc plates consisted of plasticized cellulose acetate. The composition, method of preparing the composition and method of shaping the composition into permanently restricted propellant grains is described on pages 11 and 12 of the co-pending application of William G. Stanley entitled "Restrict Solid Propellant Grain," Serial No. 549,275, filed November 28, 1955.

To one of the prepared grains was applied a single layer coating of short-term restrictor consisting of pressure-sensitive flat-back paper tape having a width of 3/4 inch and a thickness of 0.006 inch, the tape being positioned at one end of the grain immediately adjacent the periphery of the permanent restrictor disc around the external cylindrical surface of the grain. A second grain of the above series of grains was provided with short-term restriction by applying two layers of the above paper tape adjacent the permanent restrictor disc thus providing this grain with a short-term restrictor of 3/4 inch width and approximately 0.012 inch thickness around the external cylindrical surface. A third grain of the above series was used as a control grain, that is, the grain was provided only with permanent annular end restrictor discs and not with short-term restrictor tape coating.

The above grains were fired separately at 70°F grain temperature in a test motor having a gas efflux diameter of 0.236 inch using the same amounts of the same igniter charge to ignite the grains. The grains, provided with short-term restrictor, were positioned in the motor with the tape-restricted section being at the end thereof most remote from the firing end of the motor. Figures 6, 7 and 8 show photographic reproduction of the actual pressure-time traces of the burning of the three grains.

The critical period of excess gas pressure which produces the undesirable excess impact torque in the operation of an auxiliary starter turbine for a turbojet engine...
is usually the time interval between about 0.2 and 0.3 seconds following initial production of gas from the ignition of the igniter charge when the grain is fired at about 70°F, grain temperature. The maximum pressure during this period should not exceed about 1080 p.s.i.g. when the grain is fired at 70°F, grain temperature.

Referring to Figures 6, 7 and 8, Figure 6 is the trace of the firing of the control grain, which was not provided with short-term restrictor, Figure 7 is the firing trace of the grain provided with a single layer of the paper backed tape and Figure 8 is the trace of the grain having double thickness of the tape applied thereto. Pressures developed are indicated on the vertical axes and time intervals are indicated on the horizontal axes. The legend at the top of Figure 6 indicates the time interval of 3 seconds for 15 divisions, that is 0.2 second for each division which scale is the same for Figures 7 and 8.

The trace of Figure 6 shows a maximum initial pressure of about 1360 p.s.i.g. with pressure of about 1320 p.s.i.g. in critical period of 0.2–0.3 second after firing of the igniter charge.

Comparing the trace of the firing of single thickness tape restricted grain, Figure 7, with the trace of Figure 6, the maximum pressure occurring in the 0.2–0.3 second critical period was 1000 p.s.i.g. The residence time of the short-term restrictor in the firing of the grain was about one second.

The effect of increasing the thickness of the short-term restrictor is shown in Figure 8. The maximum pressure over the 0.2–0.3 second critical period was about 1080 p.s.i.g. Doubling the thickness of short-term restrictor applied increased the residence time to about 1.6 seconds, that is doubling the thickness increased the residence time of this short-term restrictor by about 60%.

These Figures 6, 7 and 8 show clearly that the objects of the invention have been accomplished by the short-term restrictor application to an unsatisfactory solid propellant grain.

Having thus described my invention, I claim:

An apparatus adapted for the production of high pressure gas from the burning of a solid propellant which comprises a chamber provided with a gas discharge opening and positioned within said chamber, an igniter assembly containing a gas-producing material the burning of which affords a sustained burning of a solid propellant grain positioned within said chamber, said assembly containing an igniter means for actuating the burning of said gas-producing material, wherein said solid propellant comprises a tubular body portion comprising ammonium nitrate, oxidizable thermoplastic binder and a combustion catalyst, permanent restrictor coatings applied to the annular ends of said tubular body portion which remain on the unburned surface of the grain until that surface is substantially burned away and a short-term restrictor coating applied to the external cylindrical surface of said body portion immediately adjacent the periphery of one of said permanent restrictor coating which short-term restrictor coating is adapted to restrain burning of the body material beneath said short-term coating for a time at least substantially equal to the burn-out time of said gas-producing material and not more than 2 seconds in excess of said burn-out time and wherein said short-term restrictor coating consists of a combustible pressure sensitive tape having a thickness of about 0.006 inch.

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