Ignition Transient Control through Inhibiting of Propellant Grain

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THERE is a real need in the solid propellant industry for a simple, inexpensive means of controlling the ignition transient performance of a rocket motor. Too frequently the rate of pressure rise and/or the peak pressure of a new motor are excessive causing serious, expensive, and time-consuming delays. This note describes the feasibility of regulating the transient performance of a solid propellant rocket motor by bonding a thin layer of inert material to a portion of the initial propellant surface.[1,2] The primary function of this "inhibitor" is to reduce the erosive burning, ordinarily present in the motor during the ignition transient, by restricting the gas generation at strategic locations within the motor. A review of previous work on ignition transient control techniques indicated that the benefits of inhibiting a motor had not been systematically investigated.

Test Plan

Forty-eight critically controlled experimental rocket motors were tested to evaluate the effects of three inhibiting variables on the ignition transient performance of a rocket motor; 1) location of the inhibitor, 2) inhibitor thickness, and 3) percentage of the initial surface inhibited. Four inhibitor locations, illustrated in Figs. 1 and 2, were investigated. Inhibitor thicknesses of 0.030 and 0.060 in. were evaluated. The initial propellant surface areas were reduced 10, 20, or 30% by applying inhibitor to the surface. Two tests were conducted at each of the 24 possible combinations of variables.

Results and Discussion

The ignition transient of a typical inhibited rocket motor is shown in Fig. 3. The magnitude of the pressure-induced loading condition is decreased below that of an uninhibited motor because less gas is being generated to pressurize the motor. As the inhibitor is consumed, additional propellant surface becomes exposed and ignited, thus raising the pressure to the full operating level. However, a significant grain geometry change occurs during the period of inhibitor removal. The free volume within the chamber increases, thereby reducing the mass velocity, erosive burning, and excessive pressures ordinarily present in the uninhibited grain.

Rate of pressure rise

The rate of pressure rise is herein defined as the mean slope of the pressure-time curve for pressures between 25 and 75% of the plateau pressure, where the plateau pressure is the temporary equilibrium pressure level in the motor caused by

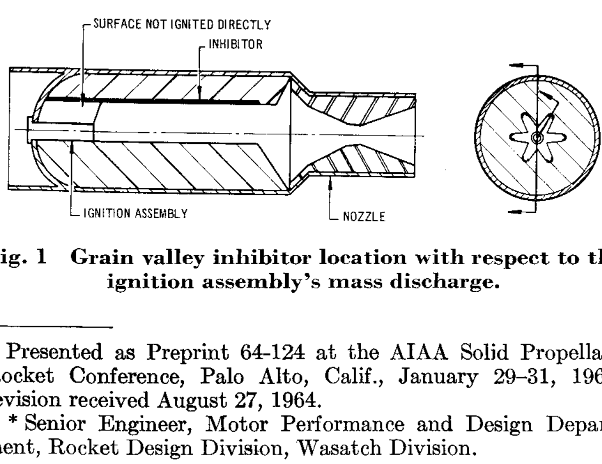

Fig. 1 Grain valley inhibitor location with respect to the ignition assembly's mass discharge.

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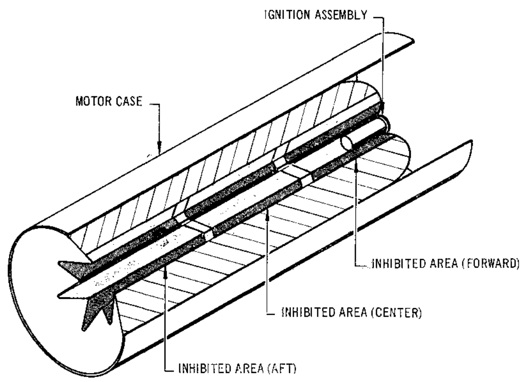

Fig. 2 Forward, center, and aft inhibitor locations with respect to the ignition assembly's mass discharge.

inhibiting (Fig. 3). Both the percentage of surface area inhibited and the inhibitor location affect the rate of pressure rise (Fig. 4). When the percentage of inhibited surface area is increased, the amount of gas generated during ignition is decreased; since the initial free volume in the chamber is essentially a constant, the rate at which this free volume is pressurized is necessarily decreased.

Of the four inhibitor locations evaluated, the head-end is the least effective location in reducing the rate of pressure rise, because the majority of the uninhibited surface is subjected directly to the ignition assembly's mass discharge (Fig. 2). Ignition thus occurs rapidly, resulting in a high rate of pressure rise. Grain-valley inhibition protects a significant portion of the surface in the aft end of the grain; furthermore, a large portion of the propellant surface in the head end of the motor is uninhibited and must be ignited indirectly by raising the pressure and temperature in the chamber instead of directly by the application of heat (Fig. 1). Therefore, the pressure rises more slowly with grain-valley inhibition than with head-end inhibition. The center region (Fig. 2) is somewhat more effective in reducing the rate of pressure rise than the grain valleys. Inhibition of the entire aft end is the most effective means of reducing the rate of pressure rise because this region normally ignites very rapidly because of direct impingement by the ignition assembly's discharge; when the aft end is inhibited (Fig. 2), only a small portion of the total uninhibited surface is ignited directly; therefore, the time delay for complete ignition of the uninhibited surface is increased, and the rate of pressurization is minimized.

Maximum pressure

The maximum pressure experienced during ignition is affected significantly by the inhibitor thickness, inhibitor location, and amount of surface area inhibited (Fig. 5). When the inhibitor thickness is increased, the greater time required to burn or erode the inhibitor allows a significant enlargement

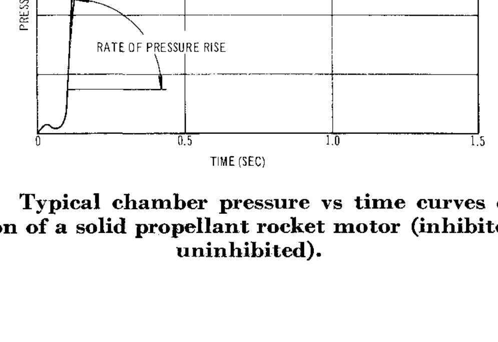

Fig. 3 Typical chamber pressure vs time curves during ignition of a solid propellant rocket motor (inhibited and uninhibited).

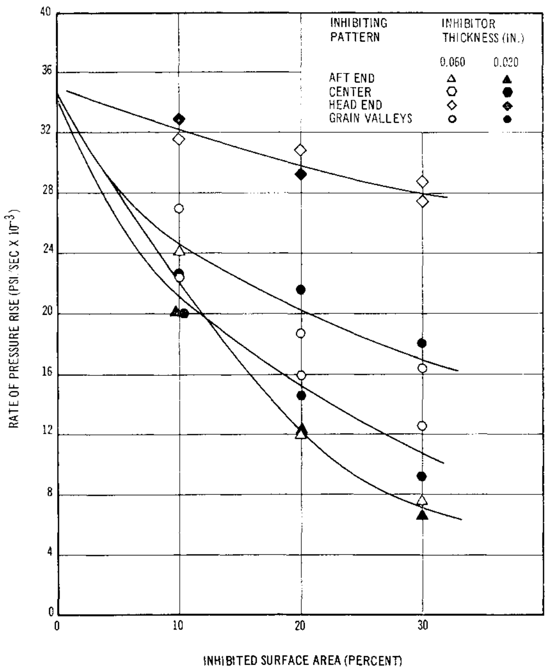

Fig. 4 Rate of pressure rise vs inhibited surface area.

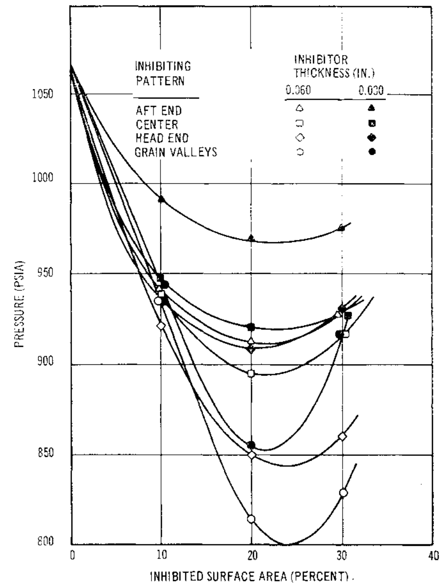

Fig. 5 Maximum chamber pressure vs inhibited surface area.

of the free volume within the grain, thereby reducing the mass velocity and the accompanying excessive pressure in the grain. Maximum pressure decreases as the inhibitor location is changed in the following order, 1) aft end, 2) center, 3) head end, and 4) grain valleys. The inhibitor is subjected to high mass velocities when located in the aft end of the grain; therefore it is eroded rapidly and uniformly causing little change in grain configuration. As the inhibitor is moved toward the head end, the mass velocity past it decreases, the inhibitor "lasts longer," the remainder of the grain enlarges more prior to the removal of the inhibitor, and the erosive burning and peak pressure are reduced.

At every inhibitor location or thickness, a minimum exists in the curve for maximum chamber pressure vs percentage of surface area inhibited (Fig. 5). To explain this observation, a working parameter had to be found that would measure the magnitude of the changes in the internal geometry of the grain prior to complete ignition of the entire grain. The only direct measurement available from the test data was the accumulated pressure-time integral, which is theoretically a function of the amount of propellant expended, and hence the increase in the free volume in the chamber, up to any given time. Evaluation of the test data verified that, for each of the eight combinations of inhibitor thickness and location tested, the pressure-time integral up to the time for maximum pressure did pass through a maximum as the percentage of the surface inhibited was increased. A further qualitative explanation is as follows. When a small amount of a surface is inhibited, higher average mass velocities are reached in the grain, and the inhibitor is rapidly removed, resulting in only minor changes in grain configuration and maximum pressure. When too large a percentage of the surface is inhibited, this large area, upon inhibitor removal, is suddenly subjected to high-level mass velocities at a relatively high pressure, and its late but rapid burning leads to a high maximum pressure. Between these two extreme conditions, an optimum tradeoff exists between the high mass velocities in the previously inhibited regions of the grain and the low mass velocities in the uninhibited regions.

Concluding Remarks

The rate of pressure rise and maximum chamber pressure in a solid propellant rocket motor can be regulated by selectively coating or inhibiting a portion of the initial propellant. Each of 24 combinations of inhibitor locations, inhibitor thickness, and percentage of surface area covered produced separate and distinct results. The initial pressure peak varied from 1060 to 820 psia, and the rate of pressure rise varied from 7000 to 35,000 psi/sec in motors of otherwise identical design.

By such surface inhibition, the cause of undesirable transient characteristics is eliminated directly without sacrificing motor performance or necessitating basic motor design changes. The data obtained in this program can be used to curb arbitrary or intuitive approaches to the design of inhibiting patterns. The practicality of these procedures has been demonstrated in now operational systems.

References

[1] Gibby, H. E., "The control of ignition transients through propellant grain inhibiting," AIAA Preprint 64-124 (1964).

[2] Wall, B., "Method and device for inhibiting a solid propellant charge," Thiokol Chemical Corp., Wasatch Div. Tech. Disclosure (September 23, 1960)