Admittance Measurements of Solid Propellants by an Acoustic Oscillator Technique

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A dynamic acoustic oscillator technique has been developed for measuring the response of a burning solid propellant surface The experimental arrangement essentially consists of a centrally vented cavity with propellant at one end and a phase-locked mechanical driver, which excites the cavity in a resonant mode, at the other end The bandwidth or Q of the resonance is determined by phase modulation of the mechanical driver and measurement of the resultant side-band amplitudes An independent method for measuring the decay constant of the cavity incorporated into this system involves momentarily shorting out the drive system and observing the free-decay or growth of the oscillations Although the apparatus was designed primarily for investigation of stable or marginally stable propellant systems, it can also be used with unstable propellant systems by introducing a 180° phase shift in the drive circuit whenever the amplitude exceeds a predetermined value Experiments are described in which lock-on to resonance was achieved and maintained for runs of several seconds duration The oscillation amplitude and Q are generally not constant, but change appreciably and irregularly during a run indicating that the damping of the cavity is undergoing substantial variations

Nomenclature

c = velocity of sound in gas
D = drive amplitude
f = frequency
Δf = bandwidth
F = carrier frequency
F_m = modulation frequency
k_1 = ratio of drive amplitudes; k_2 = ratio of pressure amplitudes
l = length of cavity
P = acoustic pressure
$\bar{P}$ = mean chamber pressure
Q = quality factor of a resonance
r = linear burning rate of propellant
t = time
$\bar{v}$ = mean gas velocity
y = real part of reduced specific acoustic admittance
Y = real part of specific acoustic admittance
α = decay constant (negative α corresponds to a growth constant)
α_D = decay constant without propellant, but with gas flow
α_D' = decay constant at propellant burnout
θ = phase angle
$\Delta\phi$ = maximum phase deviation
γ = ratio of specific heats, c_p/c_v
ρ = density of gas
ρ_s = density of solid propellant
μ/ϵ = real part of propellant response function

Introduction

THE acoustic response of the surface of the burning propellant has been shown[1–4] to play a dominant role in determining whether a solid propellant rocket motor will be stable or unstable A rather good theoretical understanding of the acoustic gains and losses in rocket motors has evolved, and it has been established that the major source of acoustic amplification is the burning propellant surface The other acoustic sources and sinks, such as viscoelastic losses in the solid propellant, damping by product gases, particle damping, wall damping, nozzle losses, and conversion of flow energy to mechanical energy can be analyzed, and their effects can be predicted with moderate accuracy The amplification properties of the burning surface, as characterized by its specific acoustic admittance, however, are not so readily amenable to calculation For this reason, a major goal of the experimental programs on solid propellant combustion instability has been the measurement of the acoustic admittance of the burning surface

If a propellant is sufficiently unstable, it can produce self-excited oscillations in combustion chambers, and from the rates of growth and decay of these oscillations it is possible, on the assumption that the acoustic damping is the same during the growth and decay periods, to calculate the acoustic admittance of the burning surface This method has been applied to unstable propellant systems with considerable success[5–9]

The acoustic oscillator technique described in this paper was designed primarily to study the acoustic response of stable or marginally stable propellant systems This, of course, represents the domain of interest for the designer of practical solid propellant rocket motors, since he probably would not knowingly incorporate an unstable propellant in a motor Even with stable propellants, however, it has not been possible previously to assess the margin of stability of a system and, therefore, to predict whether some minor design change might lead to instability The method developed in this work uses an external source of acoustic energy to excite the oscillations and affords a direct means for measuring of the margin of stability of the system

A simplified schematic diagram of the apparatus is shown in Fig 1 The propellant is placed at one end of a centrally vented cavity (T-burner), and a microphone and a mechanical driver that excites the cavity in an axial mode are at the other end The electronic system uses the cavity as the frequency-determining element of an oscillator and measures the bandwidth or Q of the resonances by a phase-modulation technique An alternative method of measuring the cavity response, which has the merit of intrinsic simplicity and has proved to be very useful, involves interrupting the power of the driver momentarily and observing the free-decay of the oscillations

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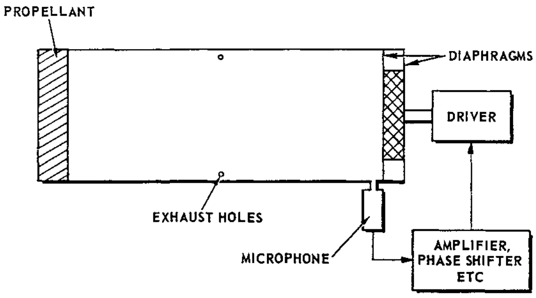

Fig 1 Simplified schematic diagram of an acoustic oscillator for measuring response of a solid propellant

The decay constant α, bandwith Δf, and Q for a resonance at frequency f are related by

$$\alpha = \pi f/Q = \pi(\Delta f) \tag{1}$$

so that any one of these parameters can be used to describe the cavity response for a stable system In the case of a self-excited oscillator the use of bandwidth and Q are inappropriate, and the cavity response is characterized by a growth constant (negative α) If the decay constant for the cavity with burning propellant is α and the decay constant without propellant but with all other conditions the same is α_D, then the real part of the specific acoustic admittance Y for a single-ended propellant system is given by

$$Y = (l/\rho c^2)(\alpha - \alpha_D)$$

where l is the cavity length, ρ is the gas density, and c is the velocity of sound; the real part of the reduced specific acoustic admittance $y = -Y(\bar{P}/\bar{v})$ is given by

$$y = -(\bar{P}l/\rho_s rc^2)(\alpha - \alpha_D) \tag{2}$$

where $\bar{P}$ is the mean chamber pressure, ρ_s is the density of the propellant, and r is the linear burning rate of the propellant In principle, it is desired that α and α_D should be measured simultaneously, a requirement that can hardly be satisfied in a practical apparatus What has been done is to measure the damping constant at propellant burnout at which time the gas flow conditions have changed materially from those existing during the burning period The conversion of mechanical energy of flow into acoustical energy when the propellant is burning has been shown by McClure, Hart, and Cantrell[10] to introduce a correction term equal to $1/\gamma$ in the measurement of y so that

$$y + (1/\gamma) = -(\bar{P}l/\rho_s rc^2)(\alpha - \alpha_D')$$

where α_D' is the decay constant at burnout when the mean gas flow has ceased Since $y = (\mu/\theta) - (1/\gamma)$, this means that in such an experiment one would actually be measuring the real part of the propellant response function μ/θ (the fractional increase in burning rate to the fractional increase in acoustic pressure) by

$$\mu/\epsilon = -(\bar{P}l/\rho\, rc^2)(\alpha - \alpha_D') \tag{3}$$

It is usually assumed that the cavity damping remains unchanged throughout a run so that measurements at burnout, α_D', can be applied to earlier parts of the run It will be shown that this assumption generally is not valid and may introduce substantial errors

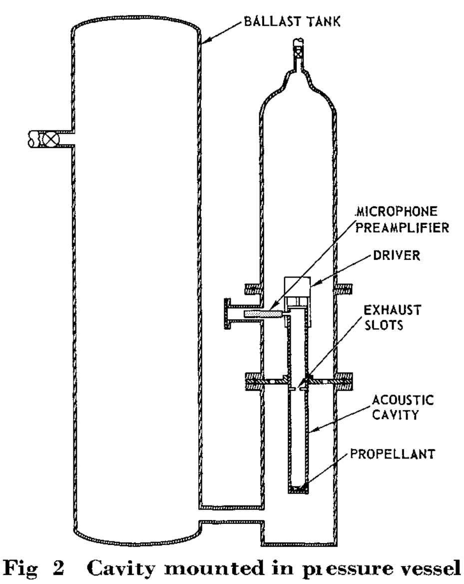

Fig 2 Cavity mounted in pressure vessel

Experimental Arrangement

Two versions of the acoustic cavity have been used in the experiment The earlier model essentially was a steel pipe 2 00-in i d × $\frac{1}{4}$-in wall, 20 0 in in length, closed at the ends and with approximately 200 holes, $\frac{1}{16}$ in in diameter, symmetrically spaced in three circumferential rings at the center of the cavity to vent propellant gases In later experiments, ceramic liners of vitreous refractory mullite (2 00-in i d × $\frac{1}{8}$-in wall) extending $7\frac{1}{2}$ in on both sides of the exhaust holes were epoxy cemented into a similar cavity in an effort to reduce cooling by the walls The exhaust configuration was changed from the series of small holes to four $\frac{1}{16}$-in -wide slots in the circumference of the tube with $\frac{1}{4}$-in spacing to accommodate a steel supporting structure When a propellant is burned, there is a large temperature asymmetry between the two halves of the cavity In order to position the exhaust slots approximately at the nodal plane for pressure antisymmetric axial modes, a 5-in extension was added to the propellant section in the latest experiments

Some comment should be made on the effect of this asymmetry on cavity Q At 200 psi pressure of nitrogen, the symmetric 20-in -long cavity has a Q of 264 for the lowest mode The asymmetrical 25-in cavity under the same conditions has a Q of 170 Taking into account the theoretical $f^{1/2}$ dependence of Q, it is found that the effect of positioning the holes off center is to lower the Q by 28% Since the important measurements are made when the propellant is burning, it was decided to optimize the geometry for this case, although this disturbed the preburn calibration of the electronic instrumentation

The cavity was mounted vertically inside a pressure vessel as indicated in Fig 2 The large conductance of the exhaust slots assured pressure equalization between the inside and outside of the cavity and permitted the use of sensitive microphones for sound pressure measurements In the particular experiments reported here in detail, the microphone was a water-cooled Altec-Lansing type 21BR 200-2, which is linear in response up to 185 db The mechanical driver was a Goodmans Industries Model V-47 vibration generator with a peak force capability of 2 lb, mass loaded with about 400 g so that the drive system would be effectively mass controlled and, therefore, unaffected by acoustic reactions from the cavity Thin stainless-steel diaphragms sealed the top of the cavity against gas leakage and transmitted the driver motion In addition to supporting the cavity, the mounting plate in the pressure vessel served as a gas deflector to prevent the hot propellant gas from reaching the electronic equipment in the upper section

The propellants, generously supplied by the Allegany Ballistics Laboratory, were intentionally oversized by several thousandths of an inch and had to be cooled prior to loading into the propellant chamber On warming to room temperature, the propellant made a tight press fit The ignition arrangement consisted of a nichrome wire 0 006 in in diameter tacked to the propellant surface at a few points with a minimum of Duco cement and a light sprinkling of black powder Firing was done by switching either a 110- or 220-v a c line across the nichrome wire

The ballast tank increased the total volume of the system to about 12 ft^3 and limited the over-all pressure rise produced by propellant burning in a typical run to about 10 psi Prior to firing, the entire system was pressurized to 200 psi with super-dry nitrogen

Acoustic Oscillator System

A phase-locked acoustic oscillator system has been developed in which the audio cavity containing the propellant is the frequency-determining element This system is capable of following rapid changes in frequency such as occur following propellant ignition or burnout A simplified block diagram of the apparatus is shown in Fig 3

Assume that the system has been adjusted so that the driver is exciting the audio cavity at a selected resonance The acoustic signal is received by the microphone, amplified, and sent to a phase-locked tracking filter (Interstate Electronics model VIII-A), which removes any extraneous signals and produces an audio signal at the driver frequency The signal then goes through a transformer and a power amplifier, closing the main feedback loop (shown by heavy lines in Fig 3)

The first problem to be solved is centering the driver frequency precisely on the resonance maximum An associated problem is the measurement of the bandwidth of the resonance For these purposes, a phase modulation technique has been devised The tracking filter contains a 250-kc crystal oscillator and a voltage-controlled oscillator, the frequency of which is constrained by a feedback loop to be 250 kc above the incoming signal frequency, so that, when the two oscillator outputs are mixed, a signal is obtained at the input frequency In the system used here, a low-frequency modulation F_m is applied by a phase modulator to the 250-kc output from the crystal oscillator so that output from the tracking filter is phase-modulated, the voltage having the form $V = V_0 \sin[2\pi Ft + \Delta\phi \sin(2\pi F_m t + \theta)]$ with corresponding maximum range of instantaneous frequencies of $F \pm F_m(\Delta\phi)$, where F is the carrier frequency, $\Delta\phi$ is the maximum phase deviation, and θ is a phase angle For the low-modulation indices employed, it is an excellent approximation to represent the signal as the sum of a carrier wave at frequency F and two side-band signals at frequencies $F \pm F_m$ Upon transmission through the audio cavity, the signal is modified by the resonant properties of the cavity to produce a maximum range of instantaneous frequencies given by $F[1 \pm (\Delta\phi/2Q)]$ If the drive frequency F is not on the center of the resonance, an amplitude modulation appears at the microphone output This is extracted by an AM detector and drives a servo system that adjusts the phase shifter, a capacitor-type continuous rotation transducer (Variogon Model 59), to bring the frequency back to exact resonance

The bandwidth is determined by a phase detector that measures the amplitude of the side-bands at $F \pm F_m$ The resonant cavity has the property of reducing the side-band amplitudes by the factor $\Delta f/2F_m$, where Δf is the bandwidth The bandwidth readout can be independently calibrated before a run by direct measurement of the frequencies at the half-power points with a frequency counter Another phase detector compares the audio signal from the microphone with the signal used to drive the cavity and thus gives a direct reading of the amplitude of the oscillations

Free-decay measurements of cavity damping are made by using a relay to short out the driver signal periodically for a specified short time interval The operation of this relay is synchronized with other operations in the experiment by a time-mark generator and frequency divider

For unstable propellants, an amplitude limiting mode of operation has been used to measure decay constants or growth constants A Schmitt trigger is used to activate a relay that reverses the phase of the driver and simultaneously changes the level of drive whenever the amplitude exceeds a predetermined value When the amplitude is driven down by re-

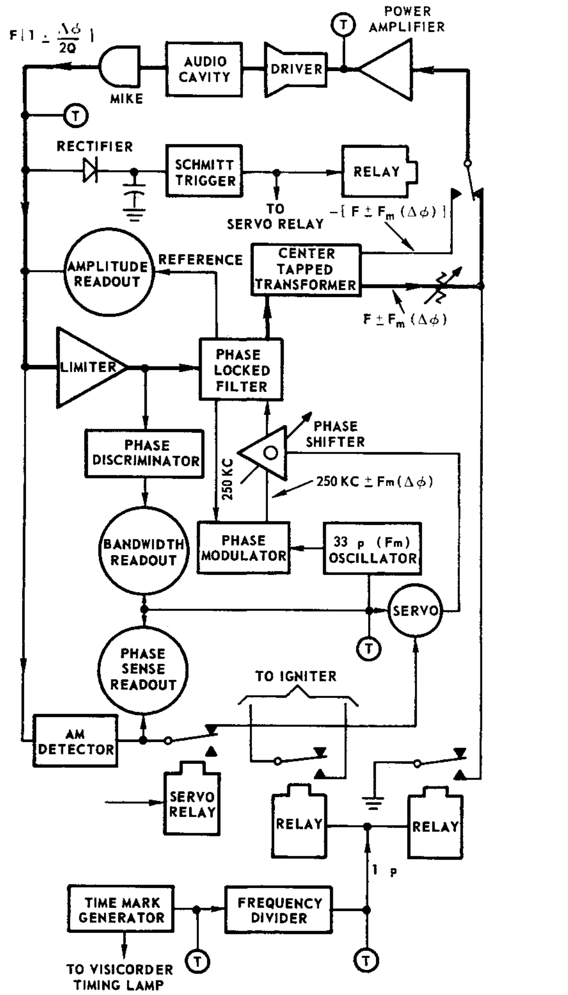

Fig 3 Schematic diagram of phase-locked acoustic oscillator system; circles labeled *T* are tape recorder inputs

versed phase operation to another preset level, the Schmitt trigger reverses the relay position and allows the amplitude to increase During the reversed phase operation of the system, the phase shifting servo is deactivated Also, the option for free-decay type of operation is likewise deactivated during reversed phase driving This is to eliminate the possibility that the amplitude could get out of control during such an interval

Data are recorded on a seven-channel Precision Instrument Company tape recorder and on a direct recording model 1508 Visicorder Oscillograph The tape recorded data can be replayed to examine in greater detail, or in expanded time scale, certain features that may not be adequately resolved on the original oscillograph records

In the case of stable propellant systems, the free-decay method of measuring damping was used as illustrated in Fig 4 Assume the system has an equilibrium acoustic amplitude P_0 The drive is shorted out for a time interval t_1 during

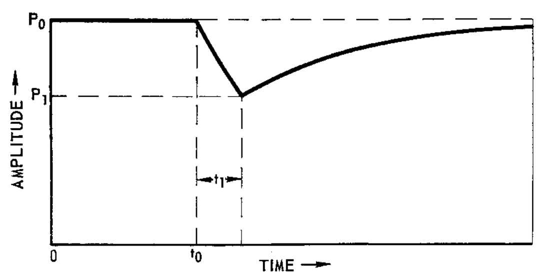

Fig 4 Free-decay measurement of decay constant

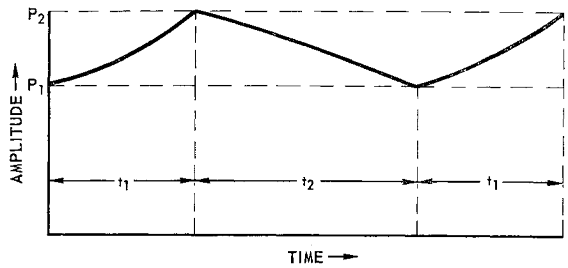

Fig 5 Amplitude limiting system used with unstable propellant systems

which the amplitude drops to P_1, and then the driver is switched back on The decay constant α is given, in this case, by

$$\alpha = (1/t_1) \ln(P_0/P_1) \tag{4}$$

In the case of unstable propellants, an amplitude limiting system was used to obtain the value of the growth constant Consider a system that is being cycled, as indicated in Fig 5, between the pressure levels P_1 and P_2 by 180° phase shifting of the driver The equations describing the pressure amplitude are

$$dP/dt = -P\alpha + D_1 \tag{5}$$

for the increasing mode (t_1), and

$$dP/dt = -P\alpha - D_2 \tag{6}$$

for the decreasing mode (t_2), where $-\alpha$ is the growth constant, and D_1 and D_2 are, respectively, the driver levels at 0° phase shift and ±180° phase shift The solutions of Eqs (5) and (6) are, respectively,

$$\begin{aligned} P &= [P_1 - (D_1/\alpha)]e^{-\alpha t} + (D_1/\alpha) \\ P &= [P_2 + (D_2/\alpha)]e^{-\alpha t} - (D_2/\alpha) \end{aligned} \tag{7}$$

where t, in each case, is measured from the instant at which driver switching occurs In terms of the known parameters $D_2/D_1 = k_1$, $P_2/P_1 = k_2$, and the measured growth and decay times t_1 and t_2, we obtain

$$(k_1 + 1)e^{-\alpha t_1} - (k_2 + k_1)e^{-\alpha(t_1+t_2)} + k_2(k_1 + 1)e^{-\alpha t_2} = 1 + k_1k_2 \tag{8}$$

as an equation for the determination of α Solutions of this exponential equation are readily obtained by an iterative procedure

Results

Both stable and unstable propellant systems have been studied by the acoustic oscillator technique In the case of a stable propellant system, acoustic energy from the drive system is necessary to maintain oscillation, and there is no possibility that the system may get out of control In the case of an unstable propellant system, however, either a failure to achieve lock-on to the resonance or inadequate programing of the reversed phase drive operation could result in run away and dangerously high acoustic levels

Stable Propellant Systems

The propellant used in these experiments was DQO, a conventional double base composition consisting of nitroglycerin, nitrocellulose, triacetin, and 2-nitrodiphenylamine Tests were run with cylindrical samples 2 0 in in diameter and lengths from $\frac{1}{2}$–$1\frac{1}{2}$ in The propellant was coated with inhibitor on the side and bottom surfaces

An oscillograph record showing the general features of a typical experiment is shown in Fig 6 This run was for a $1\frac{1}{2}$ in -long propellant that had a burning time of 13 5 sec The drive system was periodically shorted out for 0 0573 sec at 1 sec intervals during the first 10 sec of the run for free-decay measurements and then left uninterrupted so as not to interfere with observations at burnout A number of features are worth noting Temperature equilibrium is reached in approximately 2 sec, as shown by the relative constancy of the frequency of the fundamental axial mode The acoustic amplitude reaches a maximum value early in the run and then progressively decays The bandwidth reading goes through a minimum when the amplitude is a maximum and then increases monotonically

The acoustic amplitude is shown in greater detail in Fig 7, which is a playback of the microphone output The envelope of the sinusoidal oscillations shows up clearly in this presentation The driver is cut off at times indicated by the heavy lines in the figure, and the subsequent free-decay of the oscillations can be observed readily

The data provide three independent measurements of system damping: decay constant, bandwidth, and amplitude Two of these, decay constant and bandwidth, in principle provide absolute determinations, whereas the results based on amplitude require a normalization factor and may be subject to certain systematic errors In this experiment the voltage to the driver is held constant and, therefore, if the frequency and gas composition are stationary, the amplitude should be inversely proportional to the damping constant

A comparison of the three methods of measuring damping is given in Fig 8, which gives the cavity Q as a function of time during burning In general, the measurements correlate satisfactorily The free-decay measurements are definitely superior to those obtained from bandwidth over the range of Q's encountered in this experiment Some of the noise and resulting uncertainty in the bandwidth readings were caused by transients produced by the periodic pulsing of the driver

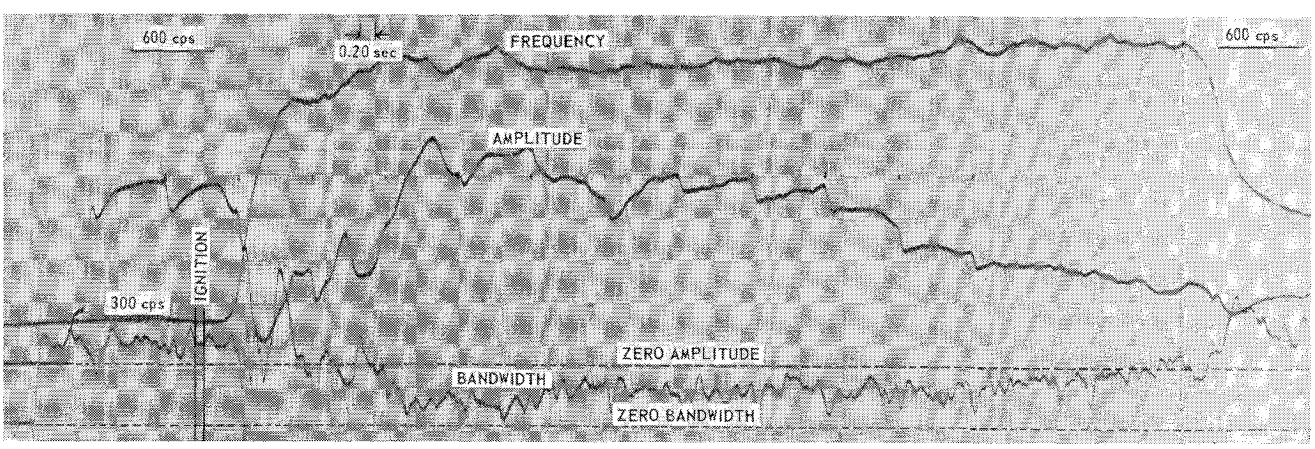

Fig 6 Oscillograph recording of amplitude, bandwidth, and frequency for DQO propellant experiment

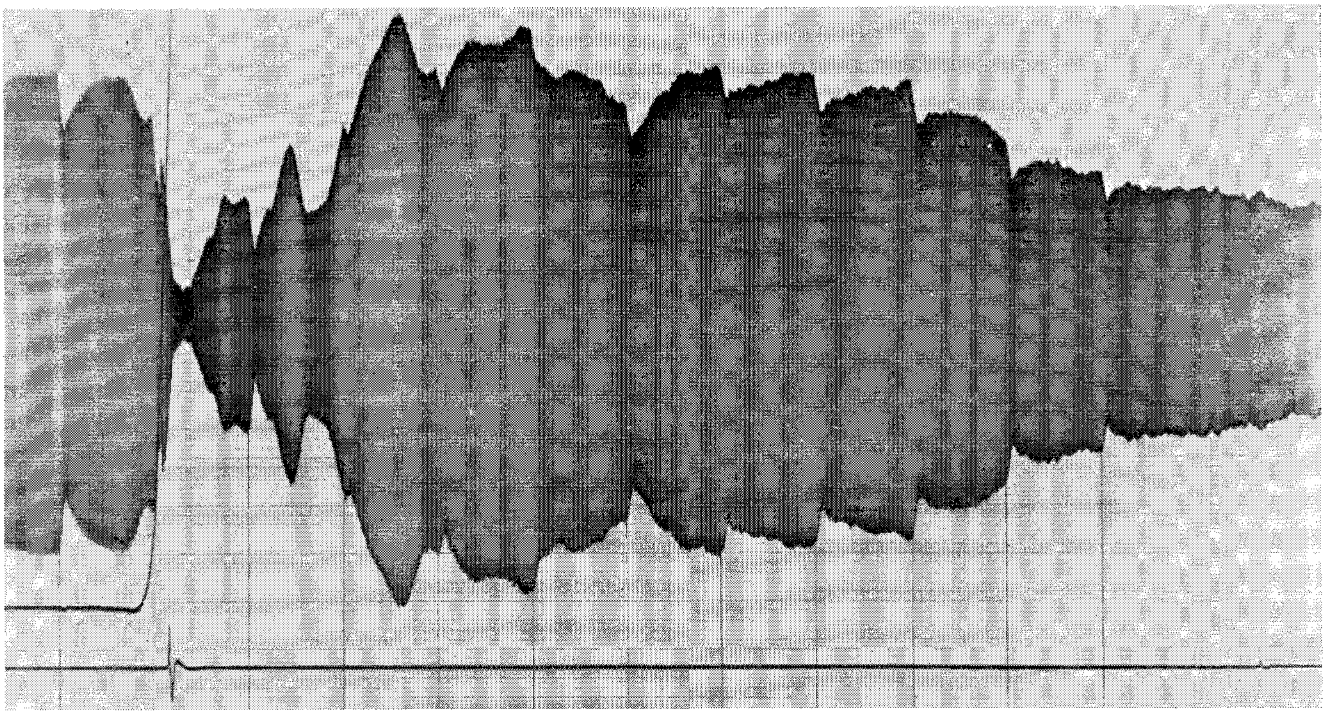

Fig 7 Amplitude of oscillations for DQO propellant as a function of time The driver is shorted out at times indicated by the heavy vertical lines

for the free-decay measurements The fact that there is good agreement between the decay constant and amplitude measurements indicates that the acoustic coupling of the driver to the cavity (ρc of the gas at the driver interface) is approximately constant during the several seconds of the run available for comparison of the data

A disturbing feature of the experiment is the continuous degradation of the cavity Q with time as manifested by decreasing amplitude and increasing bandwidth This makes it extremely difficult to estimate the cavity damping correction α_D' that should be applied to the data obtained during most of the run, particularly the interesting early period The damping measurements made after burnout can be applied with some assurance only to the burnout period An interesting observation is that there is no marked change in either amplitude or bandwidth at the instant of burnout (which is characterized in Fig 6 by a dropoff in frequency) Although there is some uncertainty in measurement, it would appear that at burnout the amplitude actually may have increased by 11% and the bandwidth decreased by some 15% This corresponds to a change in α, $(\alpha - \alpha_D') \sim 1$ sec^{-1} which, when substituted into Eq (3), gives for the propellant response function μ/ϵ a value of about $-0\ 02$ This is a very small value for propellant response and applies only to the propellant situation at burnout which may be significantly different from the propellant response in the earlier part of the run What is of considerable interest is that the method used is intrinsically capable of measuring such small propellant response functions

Unstable Propellant Systems

The propellant used was DCK, a composite double-base propellant consisting mainly of nitroglycerin, nitrocellulose, and ammonium perchlorate This propellant at 200 psi has a burning rate about $2\frac{1}{2}$ times that of DQO, so that the runs were of shorter duration

An experiment was carried out with a 2 0-in -diam × $1\frac{1}{2}$-in -long propellant using the amplitude limiting oscillatoı system previously described In Fig 9, an oscillograph record of part of the run shows the driver signal, acoustic amplitude, and analog frequency for the period of 1 5 to 3 8 sec afteı ignition The electronic system was arranged to interrupt the driver periodically for 0 045 sec at 1-sec intervals for free-decay measurements, except when the amplitude exceeded a predetermined level Two such free-decay intervals, *ab* and *kl*, are shown in the figure When the amplitude exceeded the preset upper level, the phase was automatically reversed and the drive amplitude increased by a factor of two There are four such reversed drive intervals in the experiment: *cd*, *ef*, *gh*, and *ij*

The system is almost neutrally stable at times *a* and *k*, where free-decay operation shows almost no change in amplitude In the intervening interval the system exhibits amplification Calculations have been made of the growth constants (negative α's) at different times using Eq (8) and the experimentally known constants $k_1 = 2$ and $k_2 = 1\ 29$ At time *d*, which is the earliest time when Eq (8) can be applied, $\alpha = -1\ 73$ It is of some interest to know the ratio of the reversed driver signal to the amplifier signal $-D_2/P_2\alpha$ at the instant of drive reversal This turns out to be 2 08 If we had merely reversed phase without change in drive level, the ratio would have been only 1 04, so that theıe is some doubt

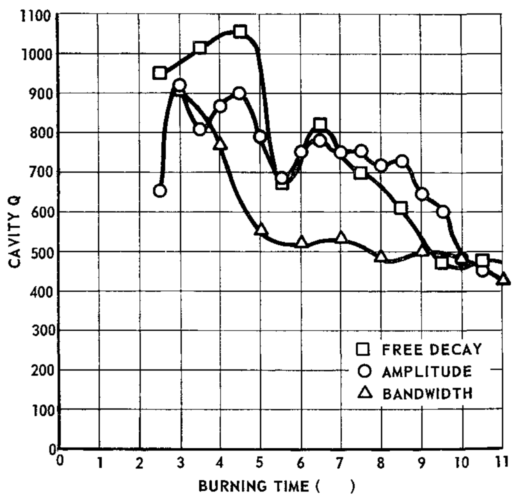

Fig 8 Comparison of *Q* measurements by free-decay, bandwidth and amplitude for DQO propellant

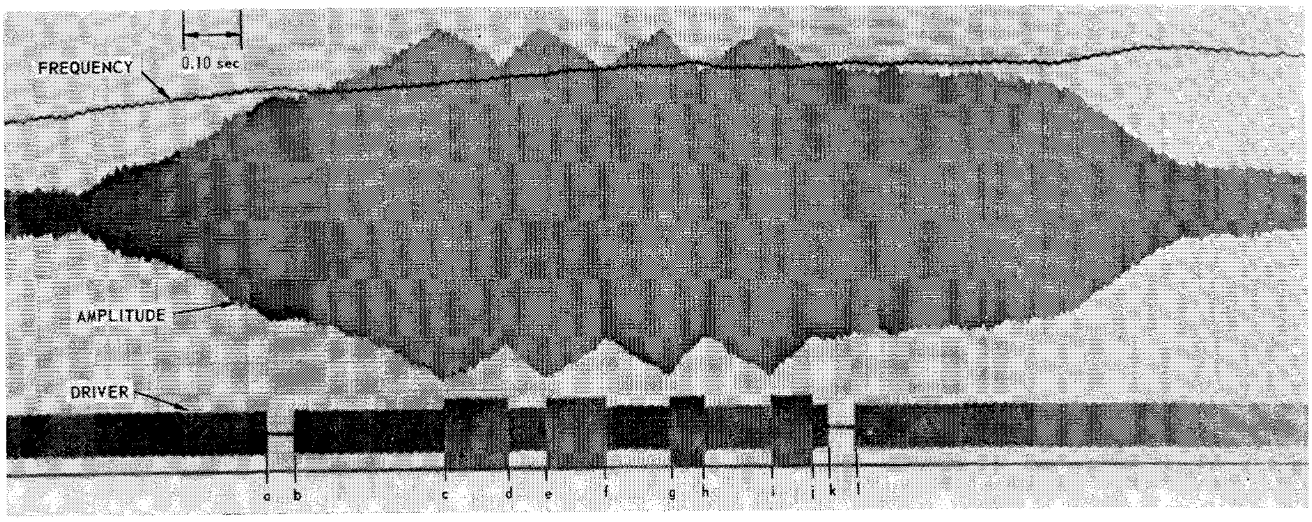

Fig 9 Oscillograph recording of amplitude, driver signal, and frequency for DCK propellant expeiiment The driver is shorted out at times *ab* and *kl* and is reversed in phase at times *cd*, *ef*, *gh*, and *ij*

as to whether the system would have remained in control The over-all amplification of the system drops off with time, a circumstance that can be qualitatively assessed by comparing the growth and decay times and noting that it progressively takes a longer time to drive the oscillations up to the reversal point and a shorter time to drive the amplitude back down The values of the growth constant at other indicated times are as follows: $\alpha = -1\ 68$ at e, $\alpha = -1\ 23$ at f, $\alpha = -0\ 13$ at g, and $\alpha = -0\ 30$ at i

For no apparent reason, the system became very lossy during the last 4 sec of the run, as shown by much reduced amplitude and more rapid free-decay of oscillations The rapid transition of the system to low-amplitude level can be seen in Fig 9 In Fig 10, the decay constant is plotted (note change in scale of ordinate) as a function of time until burnout at 7 0 sec A gradual degradation of system Q was noted in the previously discussed case of the DQO propellant In this case, however, the effect is more sudden and much larger An obvious difference between the propellants is that DCK contains ammonium perchlorate and releases considerable amounts of HCl as a combustion product It appears likely that the observed effect is due to particulate damping in the propellant gases, although the identity of the particles is unknown

As in the case of the stable propellant system, the measurements after burnout cannot be extrapolated back to the interesting part of the run shown in Fig 9 because the system subsequently undeigoes substantial changes In the DCK propellant case, the changes aie so large that we have been reluctant to make an estimate of propellant response

Discussion

It has been demonstrated that the acoustic oscillator technique can be accurately used to measure the response of a cavity containing a burning propellant as a function of time The determination of the specific acoustic admittance or, alternatively, the propellant response function requires, in addition, accurate information on the cavity damping in the absence of the propellant The measurement of this parameter presents a very formidable problem for stable or marginally unstable propellants In these cases α and α_D' are comparable, and an error in the damping constant α_D' can be reflected by Eq (3) as a large error in the propellant response function

The changes in cavity damping which greatly disturb us probably would not be noticeable in experiments with rather unstable propellants For example, in the DQO run we observed that the cavity Q changed from about 1000 to 450 (see Fig 8) during the burning interval from 2 5 to 11 sec This corresponds to a change in α from 1 8 to 4 1 sec^{-1} or $\Delta\alpha = 2\ 3$ sec^{-1} This total change is, in fact, less by at least an order of magnitude than the scatter in the values of the decay constants reported by Horton and McGie[7] for their A-1 propropellant Nevertheless, we are unable to extrapolate our data from burnout to obtain the propellant response function during the early part of the run This is because the propellant response function with which we are concerned is smaller by about two orders of magnitude than those encountered in highly unstable propellant systems

In the case of the DCK propellant, large variations in cavity damping have been observed during the run At 6 sec the decay constant reaches a maximum of 36 sec^{-1} as compared to a maximum growth rate of 1 73 sec^{-1}, so that the damping greatly overbalances the propellant amplification at this time It was thought that a decay constant as high as 36 sec^{-1} indicated a failure in the system However, a re-examination of published data on self-excited T-burners shows that damping of this order is very commonly observed In our experiment, it is clear that the damping in the early part of the run was appreciably smaller than in the latter part This suggests that some caution should be exercised in using decay measurements after burnout to correct initial growth rate data in the self-excited oscillator method of measuring propellant admittance

In several experiments with the DQO propellant, we have observed that the amplitude goes through a minimum about 0 8 sec after burnout, at which time the frequency has dropped about halfway toward the initial (cold cavity) frequency and then goes through a broad maximum that is followed by a persistent low level The broad maximum aftei burnout is expected as a result of the driver system used which becomes more efficient as the cavity cools and the fre-

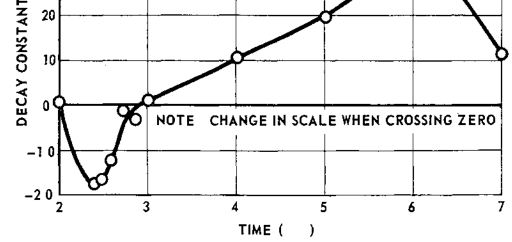

Fig 10 Decay constant as a function of time for DCK propellant test

quency drops The subsequent long-term drop in amplitude is due to damping by water vapor droplets condensing in the cavity The minimum observed after burnout corresponds to an amplitude that is less by about a factor of 2 than that expected from a smooth extrapolation of the data This indicates that the losses following burnout can become substantially higher than those operative at burnout and that damping measurements after burnout might be uncertain by perhaps a factor of two depending on the time of measurement An effect of this sort apparently has also been encountered in the usual T-burner experiments,[9] particularly at frequencies below about 2 kc, and it has been found that consistent results for propellant admittances can only be obtained by using the minimum values of the decay constants

Perhaps the most important problem remaining to be solved for stable propellants is to devise a method for accurately measuring cavity damping during the run If this can be accomplished, it would permit the precise measurement of acoustic admittance of propellant surfaces as a function of burning time

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